College of Engineering and Computer Science
**Embedded system**
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# Final project: Automatic Solar Tracker

by group 10


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# 1 Introduction

## 1.1 Background and motivation

In recent years, solar energy has emerged as a highly promising alternative to fossil fuels, which are facing shortages. Solar panels absorb sunlight, where photons excite electrons in the semiconductor material, generating an electric field that produces direct current electricity, which can then be converted into usable power. As a renewable energy source, solar energy can replenish rapidly. The energy captured by solar panels depends on factors such as sunlight duration, angle of incidence, and solar radiation intensity. Traditional solar panels are usually designed with fixed positions, which presents a limitation: they cannot maintain the optimal angle of sunlight incidence because the sun's position changes throughout the day. To maximize energy capture, the angle of sunlight should adapt to the sun's real-time position and be kept as close to perpendicular as possible.

## 1.2 Project definition and objective

The goal of our project is to design a sun-tracking system that can adaptively adjust the angle of solar panels based on the real-time position of the sun, ensuring the optimal angle for sunlight and maximizing the energy generated. We aim for a cost-effective solution by utilizing widely available components that can be easily found from the market. Additionally, our system is designed to be simple enough for easy installation at small scales, such as residential use, while also scalable for larger applications like solar farms.

## 1.3 Project Specification [1]

### 1.3.1 Functional requirement

| ID | Scope | User Requirement | Functional Requirement |
|---|---|---|---|
| FR1 | Microcontroller | The controller can capture and process sensor data correctly, and adjust the solar panel accordingly. | The Tiva C Launchpad collects and processes data in real time using ADC modules to determine the relative position of the light source. It then rotates the panel (using PWM signal) toward the sensor detecting the highest light intensity for optimal radiation capture. |
| FR2 | Sensor | The system is capable of precisely identifying the direction and intensity of sunlight. | The light-dependent resistors (LDRs) are accurately installed, and connected to the correct pins and power source, and the ADC modules are properly configured to correspond with each pin. The input signals must be sampled at an appropriate frequency to ensure continuity and accuracy without causing computational overhead for the control board. |
| FR3 | Frame | The frame is sturdy and reliable, providing support for the entire system. It must also allow the panel to rotate in alignment with the light source. | The frame is capable of supporting the battery, motor, and panel. It should be equipped with smooth rotating axes, allowing the servo motor to operate seamlessly. |
| FR4 | Power | The system is designed to operate efficiently over extended periods. | The management of resources and energy across components such as the ADC, PWM generator, and control algorithms is performance efficiently and optimally. |

Table 1: Functional Requirements.

### 1.3.2 Non-functional requirement

| ID | Requirement | Description | Scope | Detail |
|---|---|---|---|---|
| NF1 | Performance | Ensure the system operates accurately and meets real-time demands. | Entire system | • The system should detect sunlight intensity with high precision.<br>• The solar panel must continuously adjust its position to maintain optimal alignment with the sun.<br>• The servo motor should reposition the panel within 2 seconds of receiving control commands.<br>• The microcontroller must process input from the LDRs and generate appropriate control signals for the servo motor.<br>• The frame must securely hold the solar panel and actuator, allowing smooth movement. |
| NF2.1 | Reliability | **Availability:** System availability percentage. | Entire system | • In use: 90%. |
| NF2.2 | Reliability | **MTBF:** Mean Time Between Failures: Average time between system failures. | Entire system | • MTBF $>$ 2 months. |
| NF2.3 | Reliability | **Accuracy:** Required accuracy of the system output data. | Entire system | • Solar panel must be aligned within $\pm 10^o$ of the sun's position. |
| NF2.4 | Reliability | **MTTR:** Mean Time To Repair. | Entire system | • Failure resolved within 2 days. |
| NF3 | Maintainability | Facilitate easy maintenance. | Entire system | • Clean code practice.<br>• Maintenance requires $<$ 4 hours/month. |

Table 2: Non-functional requirements.

# 2 System description

An automatic solar tracker detects sunlight direction and adjusts the solar panel's position to maximize energy collection, enhancing efficiency. This system, built on the Tiva C Series LaunchPad, uses two Light Dependent Resistors (LDRs) to measure light intensity. The system also includes a servo motor that moves the panel to maintain optimal alignment with the sun.

## 2.1 Overall system

The block diagram of the system is shown below:

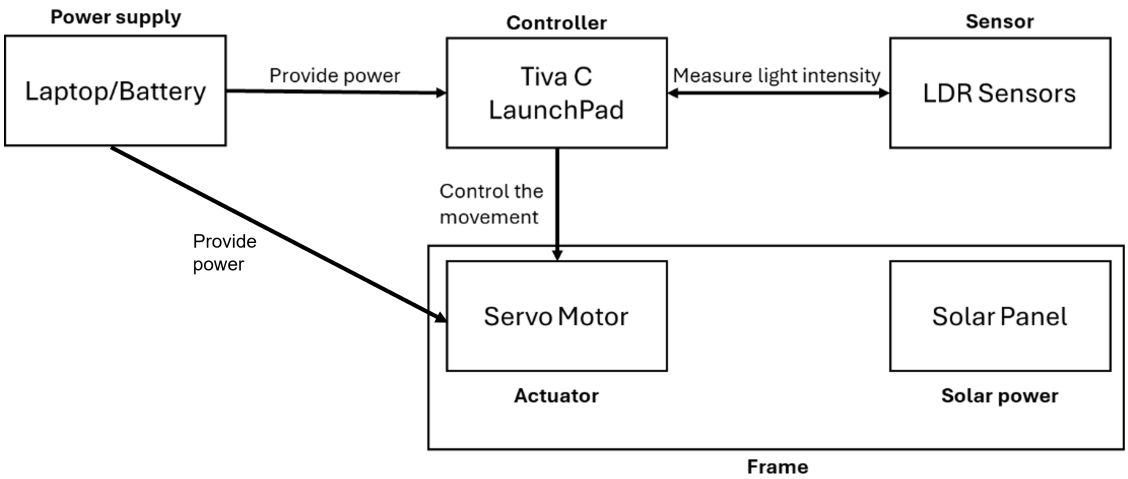



Figure 1: Block design of the system.

The block diagram illustrates the architecture of the Automatic Solar Tracker System. At its core is the Tiva C Series LaunchPad, which serves as the central processing unit. The Tiva C is powered by a laptop, while the servo will be powered by an external 6V battery to ensure functionality.

The LDR sensors are connected to the microcontroller and measure the intensity of sunlight. The sensor data is processed by the microcontroller to determine the optimal position for the solar panel. If the value of 1 LDR is significantly smaller than the other ($|\mathrm{LDR}_1 - \mathrm{LDR}_2| \geq \text{Tolerance}$), the LaunchPad will control the servo to move to the side where the value is smaller, and continue to move until $|\mathrm{LDR}_1 - \mathrm{LDR}_2| \leq \text{Tolerance}$.

The solar panel, mounted on the frame, which is connected to the actuator, aligns itself with the sun's position to maximize energy collection. The output of the solar panel is being displayed on the laptop screen via UART. The entire system is designed to ensure efficient solar tracking, enhancing energy output while minimizing power consumption.

## 2.2 Hardware structure

For this project, we have five main blocks, with each block having their own components.

- **Controller**: This microcontroller handles sensor inputs, controls the servo motor, measures the output from the solar panel and shows the output on laptop via UART.
- **Power supply**: The power for the microcontroller is supplied by the laptop, while the servo is being supplied by an external 6V battery. To control the external battery, a slide switch is implemented.
- **Light Dependent Resistors (LDRs)**: These sensors will detect sunlight intensity to determine the sun's position. The LDRs will be placed to cover the movement of the sun across the sky.
- **Servo motor**: The servo motor is used to adjust the solar panel's position based on the signal from the microcontroller.
- **Frame**: The frame is equipped with a rotational axis that allows the servo motor to adjust the panel's orientation.
- **Solar panel**: The solar panel will be mounted on the frame which has one rotational axis.

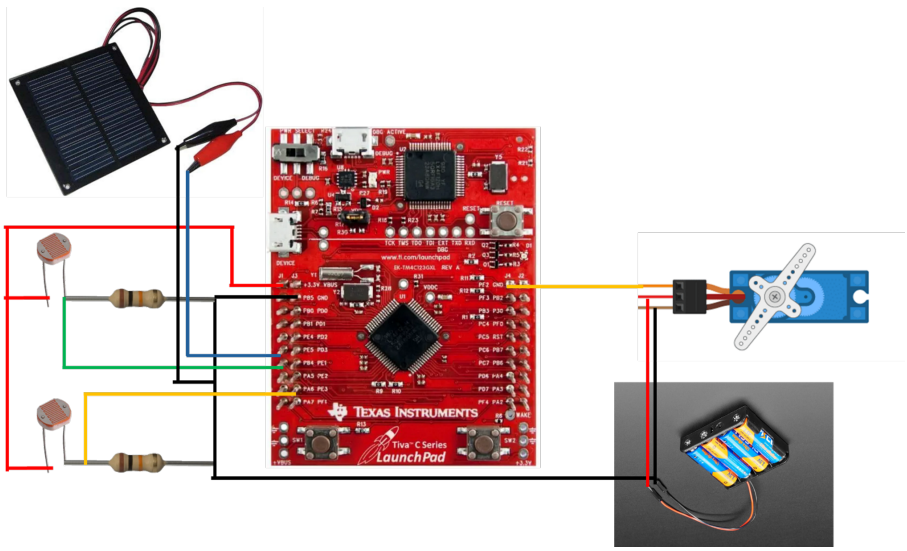



Figure 2: Connection of Components.

Figure 2 shows the physical connection of the components. The pin assignment of each component is shown in the table 3.

| Pin | Assignment |
|---|---|
| PE3 | Take ADC value of the LDR 1. |
| PE4 | Take ADC value of the LDR 2. |
| PE5 | Take ADC value of the solar panel |
| PF2 | Generate PWM signal for the motor. |

Table 3: Pin Assignment

## 2.3 Frame

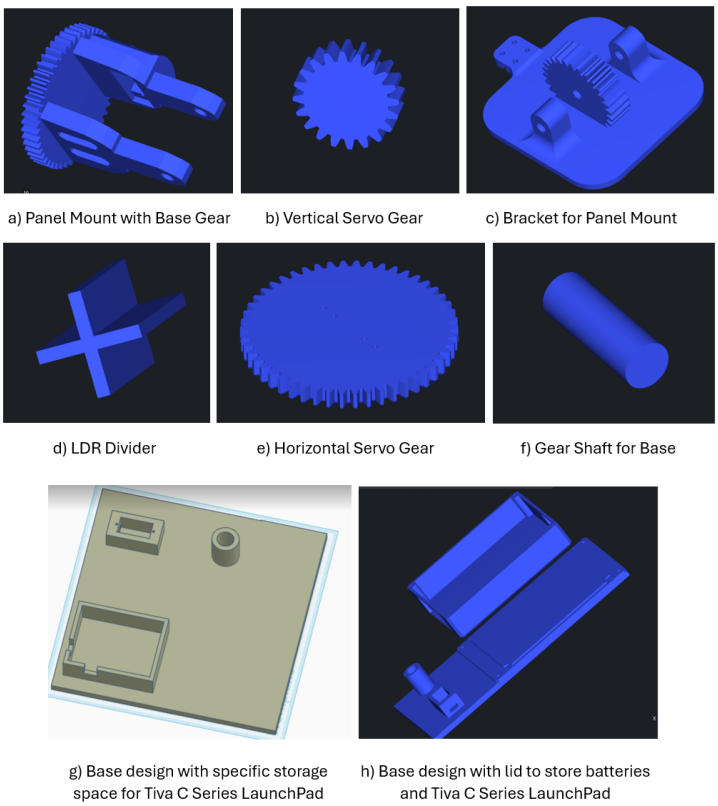



Figure 3: The 3D design of the Automatic Solar Tracker frame

Building upon existing online projects, we enhanced and adapted the design to better align with the specific requirements of our project. The frame was designed to accommodate key components with precision. The battery container, measuring 55 x 61 x 15 mm, securely holds the external battery, which powers the servo motor. The Tiva C LaunchPad, with dimensions of 65 x 50 x 40 mm, is expected to have sufficient space for wiring and connections, ensuring seamless integration into the system. From the two key dimension, we came up with two different designs for the frame. The topless configuration (Figure 2g) was selected as the final design due to its emphasis on practicality and accessibility. By eliminating the lid, this design facilitates effortless access to internal components, making maintenance, inspection, and system adjustments more straightforward. This configuration prioritizes functionality, especially in scenarios where frequent interaction with the system is required, such as prototyping and testing. Furthermore, its open structure simplifies debugging, an essential aspect during development.
As a contingency, a backup design featuring a container with a lid (Figure 2h) was also developed. This design, with dimensions of 150 x 121 x 33 mm, is compact and secure, making it well-suited for production or deployment in real-world scenarios. While this configuration offers enhanced protection and is production-ready, it sacrifices some accessibility, which may pose challenges during maintenance or modification. Nevertheless, this backup design ensures versatility, providing an alternative that is more robust and ready for field use.
The decision to proceed with the topless configuration reflects a balance between practicality and functionality. Its accessibility aligns well with the project's goals to facilitate

smooth testing and debugging processes. However, for reproduction or adaptation to different operational environments, the backup design with a lid will also be made available at the project's GitHub repository.

# 3 Software description

## 3.1 Software structure

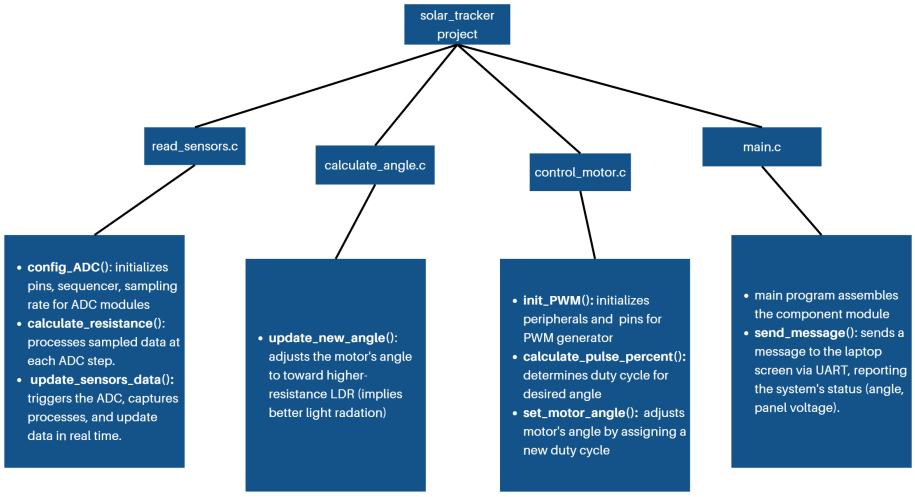



Figure 4: Software architecture

For better interpretability and reproducibility, our program is divided into smaller modules with sub-functions, as illustrated in Figure 4:

- `read_sensors.c`: This module configures the Analog-to-Digital Converter (ADC) to read and process signals from the Light-Dependent Resistors (LDRs).
- `calculate_angle.c`: Using data collected from the LDRs, it compares the resistance of the light sensors and calculates the necessary rotation angle for the solar panel.
- `control_motors.c`: This module sets up and utilizes Pulse Width Modulation (PWM) signals to control the servo motors.
- `main.c`: The main program assembles the component modules. Additionally, we designed a function to send information to a personal computer via UART. This information includes the tracker system's status, the resistance of the LDRs, and the voltage of the solar battery

## 3.2 Coding convention & Version control

In this project, we adhere to professional coding conventions. We avoid placing too many functions in a single file or creating overly complex functions, as this can lead to a codebase that is hard to understand, maintain, and debug. Instead, we organized the program into smaller, hierarchical modules, each designed to function almost independently. This modular structure simplifies debugging, updating, and reusing components for future projects.

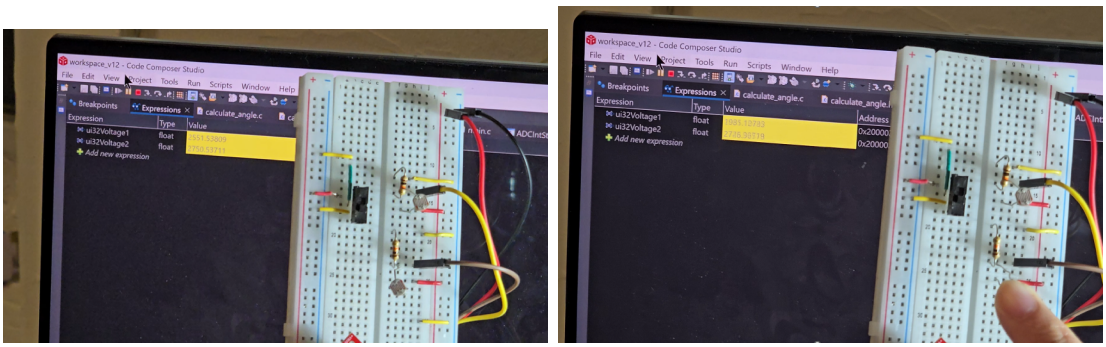
Additionally, within each module, we use dictionary-like constant variables to store configuration settings for PWM generators, ADC converters, and other components. This design allows users to easily adjust system configurations, such as I/O pins or sampling frequencies, by simply modifying these variables. This approach ensures our modules are flexible and adaptable to various designs and pin layouts.
Additionally, to facilitate teamwork and co-development of the codebase, we use Git/GitHub as the primary working environment. Team members can create their own branches to develop and test new functions without affecting the main version. These feature branches can be merged into the main branch after thorough verification. Furthermore, Git allows us to recover previous versions if any issues arise in the current version.
Our repository is organized systematically, with detailed instructions provided in the README.md file, enabling users to easily follow, reproduce, or utilize the codebase for their own projects.
Visit our codebase at: `https://github.com/anhthh2207/auto-solar-tracker.git`

# 4 Testing and Analysis

We conduct tests for the components and the system to ensure the functionality.

## 4.1 Test LDRs

First, we test the LDRs and the ADC pin of the Tiva C LaunchPad to see if it can process correctly the sensor value. For this test, we plug the LDRs into the breadboard and connect them to the controller as in figure 2. To conduct this test, we run the code which enable the ADC module for pin PE3 and PE4, and enable the breakpoint in "Update View" mode with the expressions are the voltage value of the LDR. We block the light to an LDR to see if the voltage drop.



(a) Initial setup. (b) When 1 LDR block

Figure 5: Test LDR.

## 4.2 Test Servo with LDRs

The next test involve both servo and LDRs. As we have 2 LDRs to control the movement of the servo, we will plug both LDRs and the servo to the board as in figure 2 to see if the difference in the voltage value of the LDRs will move the servo. The system will pass the test if when we block the light to an LDR, the servo move to one side, and when we block the other LDR, the servo move to the opposite side.

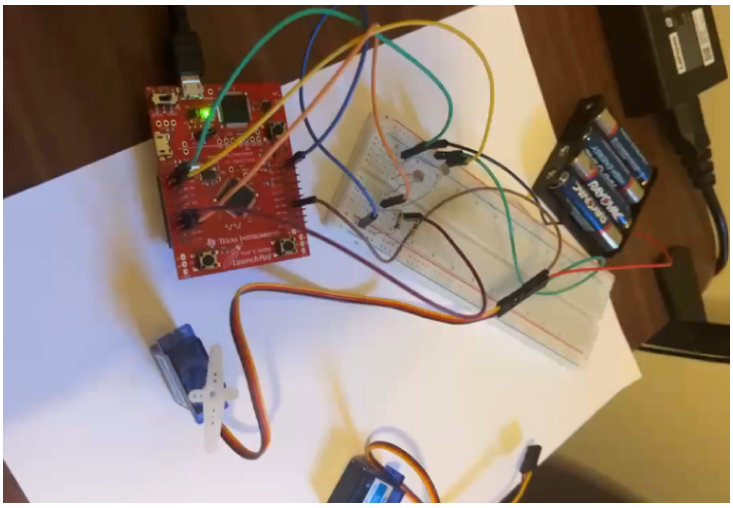


Figure 6: Initial setup for testing servo with LDRs.

### 4.3 Test entire system

To test the entire system, we integrate the electrical components with the frame and conduct test on the whole structure. For this test, we run the code that is have UART communication to send the value of LDR1, LDR2, servo position, and solar panel to Hercules to debug. The system is connected the same as in figure 2. After running the code, we use a flashlight that move along the movement axis of the solar tracker to test its ability to move the solar panel according to the position of the light source.

## 5 Result and Challenges

### 5.1 Result

The single-axis solar tracker was designed and implemented to maximize solar energy collection by tracking the sun's position throughout the day. We also successfully implement the system for real-time tracking.

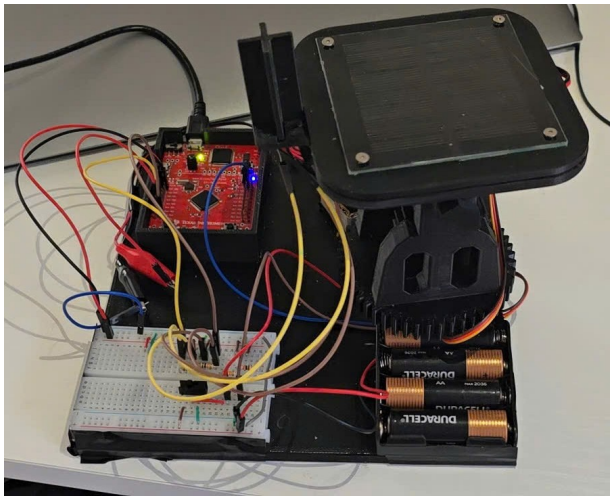


Figure 7: Single-axis solar tracker.

Future suggestion:

- Exploring dual-axis solar tracking system.
- Integrate a screen to show the energy harvested from the sun.

A demonstration of our system's performance can be viewed in the following video: `https://youtu.be/_dyrXfN8FHA`.

## 5.2 Challenges

The following are the challenges that we encounter and how we try to resolve them:

- Using breakpoint with PWM will result in incorrect operation so we use UART to communicate with Hercules to debug.
- We use a 3D design for the base, however, due to some misalignment, we cannot connect 2 gears. We are trying to fix that using cardboard and glue.
- The lab at Penn is closing for the holiday, so we do not have access to the machine/ lab supply.

# 6 Work Distribution

| Name | Role | Detailed contributions | Work % |
|---|---|---|---|
| **Tran Huy Hoang Anh** | Software Engineer | • Established and managed a collaborative environment for seamless team interaction.<br>• Developed and optimized the project codebase.<br>• Implemented version control practices. | 40% |
| **Chu Ha Linh** | System Engineer | • Modified the 3D design of the base and installed the base and components.<br>• Developed the code to test the base, recorded ADC values from the LDR, and controlled the motor. | 45% |
| **Pham Anh Quan** | Test Engineer | • Developed and modified the 3D design for the frame structure.<br>• Supported team members with code implementation, documentation, and other tasks as needed. | 15% |

Table 4: Team Contributions

# 7 Conclusion

The development and implementation of the single-axis solar tracker successfully addressed the challenge of optimizing solar energy collection by dynamically tracking the sun's position throughout the day. The project achieved real-time tracking, ensuring the solar panel maintained optimal orientation for maximum energy capture.

This project provided an excellent opportunity to broaden our skills and practical knowledge in embedded systems. By integrating hardware components such as microcontrollers, sensors, and servo motors with software control, the team gained hands-on experience in designing and implementing a complex system. The application of concepts such as real-time data processing, ADC module configuration, PWM signal generation, and UART communication underscored the practical relevance of the theoretical knowledge gained in the course. Furthermore, the project enhanced the team's understanding of debugging techniques and system optimization in embedded systems.

Throughout the development process, several challenges were encountered, including debugging issues with PWM and mechanical alignment difficulties. These were effectively resolved by using UART communication for debugging and employing creative solutions such as using glue for mechanical fixes. Despite limited access to lab facilities during the holidays, the team demonstrated adaptability and resourcefulness in overcoming obstacles.

This project highlights the potential of automated solar tracking systems in renewable energy applications. As an extension of the original proposal, the project also included a dual-axis tracking system in the demonstration video. This extension showcased the potential to further increase energy efficiency by capturing sunlight more effectively across two axes. In addition, integration of a display to monitor harvested energy in real time was proposed as a future enhancement with the aim of making the system more user-friendly and informative.

The results of this project not only contribute to the understanding of solar tracking technologies but also lay the groundwork for further advancements in sustainable energy solutions. In addition, the experience gained through this project serves as a valuable foundation to address future challenges in embedded systems and renewable energy innovations.

# References

[1] M. T. Thai. Lecture Part 9: Introduction to the course project, November 7 2024. URL `https://vinuni.instructure.com/courses/2312/files/464723?module_item_id=108858`. [Lecture slides].