**MODULE**

**PROJECT REPORT**



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**INFRARED THERMOMETER**

**WITH SIGNAL CONDITIONING**

**T.C.**

**SİVAS UNIVERSITY OF SCIENCE AND TECHNOLOGY**

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**COMPUTER ENGINEERING**

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**THE PURPOSE AND SCOPE OF THE INFRARED THERMOMETER PROJECT WITH SIGNAL CONDITIONING**

The signal conditioning infrared thermometer project aims to process and make available the signal coming from the infrared sensor to measure non-contact temperature. This includes determining the temperature range, adapting to different materials, defining the measurement distance and area, and adjusting accuracy and precision. The weak and noisy signal from the sensor is amplified, filtered and corrected if necessary. The effect of ambient temperature is reduced. The measured temperature is displayed on a screen or transferred to other systems. The project also covers power supply, physical design and testing processes.

**The Methods Used for the Infrared Thermometer Project with Signal Conditioning**

Methods include sensor selection, signal amplification/filtering/correction, data processing/display and calibration with microcontroller.

**What is an Infrared Beam?**

Infrared is invisible rays with longer wavelengths than visible red light. They are also known as infrared rays. Those that can be detected by heat detectors have the longest wavelength. Their wavelengths are approximately between 0.8 microns and 1000 microns. They do not affect normal photographic films and cannot be detected with normal optical instruments. The reason for this is that their energy is much lower than the energy of visible light. They can only be detected as a result of the heat they produce. IrDA (a technology that enables wireless data communication over short distances via infrared rays) are short-range (a few meters) and devices must see each other directly to interact.

metin, ekran görüntüsü, yazı tipi, renklilik içeren bir resim

Yapay zeka tarafından oluşturulan içerik yanlış olabilir.

***Figure 1.1***

**Discovery of Infrared**

In 1800, astronomer William Herschel set up an experimental apparatus that separated the light coming from the Sun into wavelengths through a prism. He passed each color through a separate slit and independently measured their brightness and the temperatures they caused in the thermometer.

Although the lack of equipment and scientific knowledge at that time would cause such an experiment to be questioned from many points today, the results found by Herschel were extremely surprising and led him to the discovery of infrared. With his guesses, he realized that the brightest color was a shade between yellow and green. This is indeed approximately the case when we look at the Sun's spectrum.

taslak, çizim, dış mekan, siyah beyaz içeren bir resim

Yapay zeka tarafından oluşturulan içerik yanlış olabilir. ***Figure 1.2***

What was interesting was the temperature measurement. While he expected a peak in the temperature distribution, that is, an increase followed by a decrease, he observed an increase as the red increased. This was enough to make him think that there was something beyond red. Thus, the existence of the infrared region was discovered through successive experiments.

Normally, red and infrared are a region with low frequency, that is, low energy, compared to the blue region. Of course, at that time, the energies and frequency relations of photons were not known. Therefore, Herschel interpreted this temperature increase as heating radiation. Today, due to infrared heaters, there is still a misconception that infrared has such a difference compared to others.

In fact, infrared is lower energy than visible light and is expected to heat less because it carries less energy. However, infrared heaters emit a large portion of their radiation in the infrared region due to their temperature. This situation is related to black body radiation and explains why a heated object first appears red.

**Important Aspects of Infrared Temperature Sensors:**

**• Non-contact Measurement**

Infrared sensors can measure temperature without directly contacting the object. This allows measurement without damaging the object being measured or requiring contact with the device.

**• Fast Response Time**

Infrared sensors react instantly to temperature changes. This provides a great advantage in real-time temperature monitoring and monitoring instant temperature changes.

**• Use in Harsh Environments**

Infrared sensors can operate safely in harsh conditions such as high temperatures, hazardous chemical environments or electrical conductivity. This makes them ideal for making safe measurements in hazardous areas.

**• Continuous and Long-Term Monitoring**

Infrared sensors can continuously monitor and record the surface temperature of an object. This makes it easy to monitor temperature changes in a given environment.

**• Fast and Precise Temperature Measurement**

Infrared sensors can measure temperatures with high precision and provide results very quickly. This is an important feature in areas that require high efficiency and safety.

**Usage Areas of Infrared Thermometer Sensor**

Infrared sensors are used in many fields, reflecting their wide applicability.

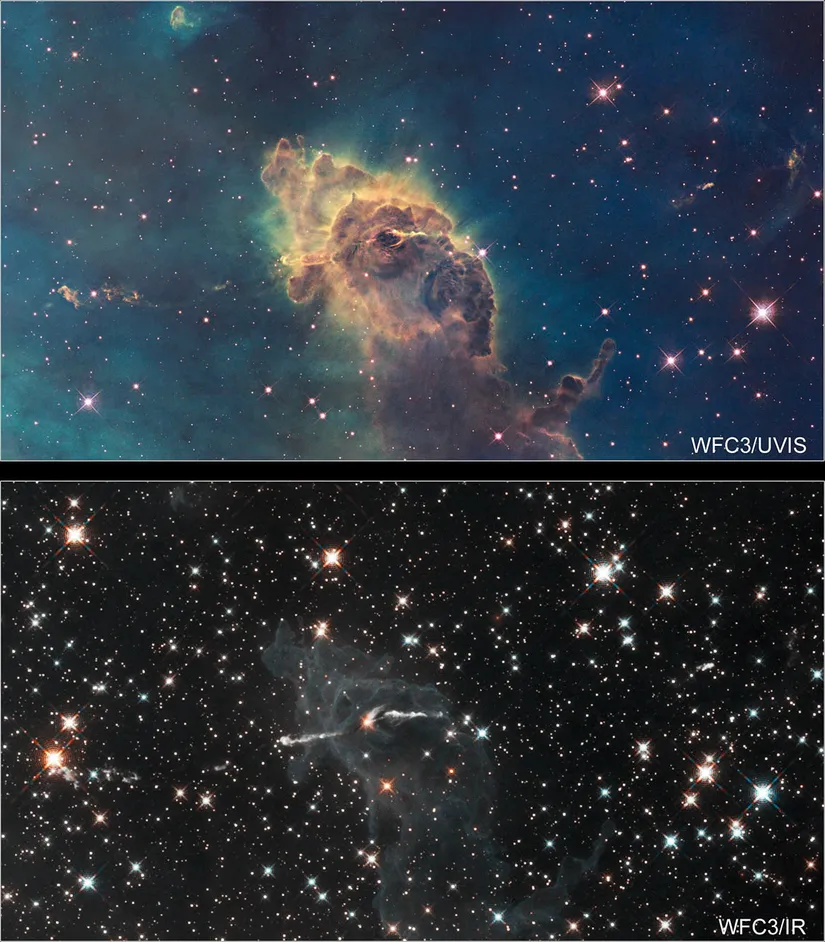
**Security**: Used in motion detectors for alarm systems.

**Automotive:** Night vision systems also include the use of infrared sensors for parking assistance.

**Industry:** In industrial automation, these sensors help detect the presence and location of objects in production lines. They facilitate remote control operations for various devices. They are also used in automatic lamps for lighting systems.

**Agriculture:** To monitor plant health, rates such as photosynthesis rate are observed with infrared cameras. The movement of night-active animals is also detected for plants.

**Astronomy:** To view areas that cannot be viewed, to find cold objects such as planets. ***Figure 1.3*** shows an image that is made clear with infrared.

****

***Figure 1.3***

**Medicine:** Infrared sensors are used in medical devices for non-contact temperature measurements. In addition, imaging systems developed using infrared sensors are used to detect local thermal changes in the human body and to diagnose diseased areas such as tumors or cancer.

Especially during World War II, objects in the dark became more noticeable by making reflected infrared rays visible. Firms that used the heat effect of such infrared rays produced ovens and lamps used in the treatment of skin diseases.



***Figure 1.4***

## **MLX90614 WORKING PRINCIPLE AND SIGNAL CONDITIONING PROCESS**

The MLX90614 is an advanced non-contact infrared (IR) temperature sensor developed by Melexis. This integrated sensor system combines a thermopile sensor, precision amplifiers, signal conditioning filters, an analog-to-digital converter (ADC), a digital signal processor (DSP), and communication interfaces into a single package.

## **Diagram of MLX90614**

The figure below shows the internal structure of the MLX90614 sensor, illustrating the signal flow from infrared detection to data output.

metin, diyagram, yazı tipi, plan içeren bir resim

Yapay zeka tarafından oluşturulan içerik yanlış olabilir.

***Figure 1.5***

Signal conditioning is the process of manipulating, converting, and preparing an analog signal from a sensor or transducer so that it can be accurately and reliably read by data acquisition systems, microcontrollers, or analog-to-digital converters (ADC).

It involves a combination of techniques such as amplification, filtering, isolation, linearization, and conversion to transform raw, low-level, noisy, or nonlinear signals into clean, standardized, and digitizable formats suitable for processing and analysis.

Signal conditioning ensures that the measured signal maintains its integrity and represents the physical quantity (such as temperature, pressure, or voltage) with high accuracy, stability, and resolution.

### IR Radyasyon → Termopil → Op-Amp (Amplifikasyon) → Filtre → ADC → DSP → Dijital Sıcaklık

### **1. Thermopile IR Sensor**

This is the first stage of the sensor that detects infrared radiation emitted by an object. It consists of multiple thermocouples connected in series to form a thermopile. The radiation absorbed causes a temperature difference between the junctions, generating a small voltage proportional to the object's temperature. This signal is typically in the millivolt range and requires amplification.

### **2. Analog Signal Amplifier (Op-Amp)**

The low-level signal from the thermopile is fed into a high-gain, low-offset chopper-stabilized operational amplifier. This amplifier boosts the signal to levels suitable for digitization, while preserving accuracy and minimizing offset drift. Differential input design ensures high immunity to common-mode noise.

### **3. Low-Pass Filter**

After amplification, the analog signal passes through a low-pass filter to eliminate high-frequency noise and electromagnetic interference (EMI). This step ensures signal stability and measurement accuracy in noisy environments***.***

### **4. Analog-to-Digital Converter (ADC)**

A 17-bit ADC digitizes the cleaned analog signal with high resolution, allowing detection of small temperature variations. The digital output is then forwarded to the DSP.

### **5. Ambient Temperature Sensor**

This component measures the internal ambient temperature of the sensor casing using a thermistor or silicon bandgap sensor. The ambient value is used in thermal calculations to determine the absolute temperature of the target object.

### **6. Digital Signal Processor (DSP)**

The DSP calculates the final temperature using the data from both the thermopile and ambient temperature sensors. It applies physical laws such as Stefan-Boltzmann’s equation, uses EEPROM-stored calibration constants, linearizes and compensates for non-linearities, and delivers the final temperature output in Celsius or Kelvin.

**Stefan-Boltzmann Law and Measurement Principle**

The MLX90614 measures the temperature of an object based on the infrared radiation it emits. The emitted radiation energy is related to the object's temperature by Stefan-Boltzmann's law:

**E = ɛ . σ . T⁴**

Where:  
- E is the emitted energy per unit area (W/m²)

- ε is the emissivity of the object (0 < ε ≤ 1) Emissivity is a dimensionless measure of how efficiently a surface emits infrared (IR) radiation compared to an ideal blackbody.  
- σ is the Stefan-Boltzmann constant (5.670 × 10⁻⁸ W/m²K⁴)  
- T is the absolute temperature (Kelvin)  
  
The thermopile within the sensor converts this radiated energy into a small analog voltage, which is then amplified, digitized, and processed by the DSP. To compensate for ambient temperature and nonlinearities, factory-calibrated correction coefficients stored in EEPROM are used.

## **EEPROM and Calibration Coefficients**

Each MLX90614 device includes a non-volatile EEPROM that stores device-specific calibration data. These parameters are used by the DSP to transform raw sensor outputs into accurate and linearized temperature readings. Below is a breakdown of the primary EEPROM-stored coefficients and their functions:

### **A0 (Address 0x20)**

Offset correction factor for the thermopile signal. It provides a base level adjustment to correct the zero-reference voltage.

### **A1 (Address 0x21)**

Gain factor applied to the thermopile signal. This determines how changes in signal level relate to changes in temperature.

### **A2 (Address 0x22)**

Second-order polynomial coefficient used to correct nonlinear response in the thermopile output. The signal is modeled as: T\_obj = A0 + A1·V + A2·V²

### **TGain (Address 0x30)**

Gain factor for the PTAT (Proportional To Absolute Temperature) signal that measures ambient temperature. It scales the PTAT output.

### **TOffset (Address 0x31)**

Offset applied to the ambient temperature PTAT signal. It ensures ambient temperature readings align with actual reference values.

### **Emissivity (Address 0x24 or 0x2E)**

Defines the emissivity coefficient (ε) used in the Stefan-Boltzmann formula. It accounts for the radiation efficiency of the object's surface.

### **I2C Address (Address 0x0E)**

Specifies the slave address of the MLX90614 on the I2C bus. Useful for multi-device configurations.

### **PWMCTRL (Address 0x22)**

Configures the behavior and resolution of the PWM output mode. It defines duty cycle interpretation for analog-equivalent output.

### **Config1 & Config2 (Addresses 0x25, 0x2F)**

Control measurement intervals, filtering behavior, and power management settings.

These EEPROM values are read by the DSP during each measurement cycle and used to compensate, calibrate, and linearize the resulting data. Adjustments must be performed carefully to avoid invalidating factory calibration.

### **7. EEPROM**

Stores factory calibration data, sensor-specific constants, I2C address, and optional user settings. It enables consistent performance and plug-and-play integration.

### **8. Communication Interface (I2C )**

Final temperature data is transmitted via I2C or interface. I2C provides reliable digital communication with microcontrollers, while PWM offers a modulated signal with temperature information encoded in duty cycle.

I2C (Inter-Integrated Circuit) is a synchronous, master-slave, two-wire serial communication protocol designed for short-distance data exchange between digital integrated circuits. It was originally developed by Philips (now NXP).

• The MLX90614 infrared temperature sensor uses the I2C protocol for communication.

* Default I2C Address: Usually 0x5A (stored in EEPROM at address 0x0E)
* Temperature and EEPROM data can be read or written via I2C using any I2C-compatible microcontroller (e.g., Arduino, STM32, ESP32).

|  |  |  |  |
| --- | --- | --- | --- |
| **MLX90614 PIN** | **FUNCTUION** | **MICROCONTROLLER**  **PIN** |  |
| VDD | POWER SUPPLY | +3.3V/+5V |
| GND | GROUND | GND |
| SDA | DATA LINE | SDA  (e.g.,A4 on Arduino Uno) |
| SCL | CLOCK LINE | SCL  (e.g.,A5 on Arduino Uno) |

**ARDUINO PINS**

**elektronik donanım, elektronik mühendisliği, elektronik bileşen, devre bileşeni içeren bir resim

Yapay zeka tarafından oluşturulan içerik yanlış olabilir.**

***Figure 1.6***

**General Inputs**

**• USB Connection:** Used for loading programs onto the card and serial communication between the card and the computer.

**• DC Power Input:** For unregulated DC power input of maximum 5-12V.

**• Reset Button:** For resetting the program loaded onto the card and starting over, there is also an input on the left of the card that serves the same purpose.

**Power Pins**

**• GND:** It is the grounding pin. There are more than one GND pin on the Arduino Uno and these pins are connected to a common ground line.

**• 5V:** It is used to provide power to the microcontroller and other components on the board. It provides an output voltage of 5V and the output current is approximately 450mA.

**• 3.3V:** It provides a supply voltage of 3.3 volts. It supports a current output of approximately 50mA.

**• VIN Pin:** It is used to provide power to the Arduino uno board using an external power supply. A voltage between 9V and 12V is used.

**Analog Pins**

**A0, A1, A2, A4, A4, A5** are 6 in total. The resolution of analog input pins is 10 bits. These pins can divide the applied voltage between 0-5V into 210 = 1024 parts, so voltage values ​​can be read with 5/1024 precision.

**• Analog Reference Pin(AREF):** It is the reference voltage for analog inputs, used with analogReference().

**Digital Pins**

The digital pins on the Arduino can be used for general purpose input and output with the pinMode(), digitalRead() and digitalWrite() commands. The maximum current per pin is 40mA.

• **Serial Input/Output:** These are pins 0(RX) and 1(TX) on the Arduino. These two pins allow the Arduino to establish serial communication. TX is the pin that sends data, and RX is the pin that receives data.

• **External Interrupts:** These are pins 2 and 3 on the Arduino. These pins can be configured to trigger a low value interrupt, a rising or falling edge, or a change in value.

• **PWM (Pulse Width Modulation):** These are pins 3, 5, 6, 9, 10 and 11 on Arduino. 8-bit PWM output can be provided in the form of square waves with a voltage between 0-5V via these pins.

• **SPI (Serial Perpheral Interface):** Pins **10** (**SS**), **11** (**MOSI**), **12** (**MISO**), **13** (**SCK**) on the Arduino. It is a synchronous serial data protocol used by microcontrollers to communicate quickly with one or more peripheral devices over a short distance. It is used for communication between two microcontrollers.

* **SS(Slave Select):** Pin used to enable or disable certain devices on the Master.
* **MOSI(Master Out Slave Out):** Master line used to send data to peripherals.
* **MISO(Master In Slave Out):** Slave line used to send data to the Master.
* **SCK(Serial Clock):** Synchronizes the transmission of data sent by the Master.

• **I2C (Inter Integrated Circuits**): It is a protocol where only two wires are used for communication. It is also called TWI (two wire interface). These two wires are **SDA (Serial Data)** and **SCL (Serial Clock).** In the I2C communication protocol, after the transmitter transmits the data, an acknowledgement is expected from the receiver to know whether the data has been successfully received by the receiver.

* **SDA(Serial Data):** line used to transmit data.
* **SCL(Serial Clock):** clock line designed to synchronize data transfers.

**ICSP(In-Circuit Serial Programming)**

These pins allow the user to program the firmware of the Arduino boards. There are six ICSP pins on the Arduino board that can be connected to a programmer device via a programming cable.

**ML90614 SENSOR DATA**

|  |  |
| --- | --- |
| **FEATURES** | **DETAILS** |
| Temperature Range | -40 … +125 ° C sensor temperature  -70 … + 380 °C object temperature |
| Measurement Resolution | 0.02 ° C |
| Output Type | PWM (Pulse Width Modulation) output |
| Digital Interface | SMBus compatible (based on I²C protocol) |

**MATERIAL AND PRICE LIST**

|  |  |  |
| --- | --- | --- |
| **MATERIAL** | **ITEM** | **PRICE(TL)** |
| Arduino UNO R3 Klon USB Kablo Hediyeli - (USB Chip CH340) | Arduino Uno R3 | 250 |
| elektronik donanım, elektronik bileşen, devre bileşeni, bilgisayar bileşeni içeren bir resim  Yapay zeka tarafından oluşturulan içerik yanlış olabilir. | 16x2 LCD Screen | 160 |
| 400 Pin Orta Boy Breadboard | BREARDBOARD | 70 |
| 4110-40 Kitronik | 4110-40, 200mm Jumper Wire Breadboard Jumper Wire in  Black, Blue, Brown, Green, Grey, Orange, Purple, Red, White, Yellow |  204-8241 | RS | JUMPER WIRES | 60 |
| boru, tüp içeren bir resim  Yapay zeka tarafından oluşturulan içerik yanlış olabilir. | MLX90614 INFRARED TEMPERATURE SENSOR | 597.77 |

**metin, ekran, görüntüleme, diyagram, dikdörtgen içeren bir resim

Yapay zeka tarafından oluşturulan içerik yanlış olabilir.CIRCUIT INSTALLATION**

***Figure 1.7***

**1. LCD Screen Connections (16x2 Character LCD)**

• The GND pin is connected directly to the GND pin on the Arduino using a dark green wire.

• The VCC pin is connected to the breadboard’s power rail via a dark pink wire, which is powered by the Arduino’s 5V output.

• The SDA pin is connected to the Arduino’s A4 (Analog 4) pin via a brown wire. This line is also shared with the SDA pin of the sensor.

• The SCL pin is connected to the Arduino’s A5 (Analog 5) pin through the breadboard using a pink wire, which is shared with the sensor’s SCL pin as well.

**2. MLX90614 Infrared Temperature Sensor Connections**

• The VIN pin is connected to the first terminal of the breadboard’s power rail via a light green wire. This rail is powered by the Arduino’s 5V output.

• The GND pin is connected directly to the Arduino’s GND pin using a purple (or dark brown) wire.

• The SDA pin is connected to the shared SDA line on the breadboard using a brown wire, which is routed to the Arduino’s A4 pin and also connected to the LCD’s SDA.

• The SCL pin is connected to the shared SCL line on the breadboard using a pink wire, which is routed to the Arduino’s A5 pin and also connected to the LCD’s SCL.

**3. Power Distribution and Shared Buses**

• The 5V output from the Arduino is connected to the positive power rail of the breadboard, which supplies both the LCD and the sensor.

• GND connections are made using separate wires for the LCD and the sensor, both going directly to the Arduino’s GND pin, ensuring a common ground reference.

• The SDA (A4) and SCL (A5) pins used for I²C communication are shared between the LCD and the sensor. This configuration is fully compliant with the I²C protocol’s support for multiple devices on the same data bus.

**Installation of the Stages**

The installation steps of the circuit are seen in ***Figure 1.8***, ***Figure 1.9***, ***Figure 1.10*** and ***Figure 1.11***.

kişi, şahıs, ofis malzemesi, giyim, çocukların yaptığı resimler içeren bir resim

Yapay zeka tarafından oluşturulan içerik yanlış olabilir.kişi, şahıs, ofis malzemesi, giyim, parmak içeren bir resim

Yapay zeka tarafından oluşturulan içerik yanlış olabilir.kol saati, saat, elektronik donanım, kişi, şahıs içeren bir resim

Yapay zeka tarafından oluşturulan içerik yanlış olabilir.

***Figure 1.8 Figure 1.9***  ***Figure 1.10***

**metin, elektronik donanım, elektronik mühendisliği, kablo içeren bir resim

Yapay zeka tarafından oluşturulan içerik yanlış olabilir.**

***Figure 1.11***

**CODE EXPLANATION FOR AN INFRARED THERMOMETER WITH SIGNAL CONDITIONING PROJECT**

**Libraries (Initial Settings):**

**metin, yazı tipi, ekran görüntüsü, çizgi içeren bir resim

Yapay zeka tarafından oluşturulan içerik yanlış olabilir.**

• **Line1:** This line incorporates the Wire library, essential for I2C (Inter-Integrated Circuit) communication, into the program. This library is mandatory as the MLX90614 sensor and the LCD screen communicate via the I2C protocol.

• **Line2:**This line includes the LiquidCrystal\_I2C library, used to control I2C-compatible LCD screens.

• **Line3:**This line incorporates the Adafruit library, specifically written for communicating with the MLX90614 infrared temperature sensor.

metin, ekran görüntüsü, yazı tipi, sayı, numara içeren bir resim

Yapay zeka tarafından oluşturulan içerik yanlış olabilir.**Object Definitions:**

• **Line6:** This line creates an lcd object for the I2C LCD screen.

* 0x27: This is the I2C address of the LCD screen. This address may vary depending on the I2C converter used.
* 16: This is the number of columns of the LCD screen (i.e., 16 characters per row).
* 2: This is the number of rows of the LCD screen (i.e., a 2-row screen).

• **Line7:**This line creates an mlx object for the MLX90614 sensor. Data will be read from the sensor through this object.

• **Line8:**This line defines a floating-point variable named temp to store the temperature value.

• **Line9:**

**Function (Initial Settings):**This function runs once when the Arduino board is powered on or reset.

• **Line10:** Initializes communication with the serial monitor. The 9600 baud rate specifies the rate at which data is read from the serial monitor.

• **Line11:**Initializes the MLX90614 sensor. This function establishes communication with the sensor and prepares it for use.

• **Line13:**Initializes the LCD screen.

• **Line16:**Turns on the backlight of the LCD screen.

• **Line18:** Sets the cursor (the position where the text will start) of the LCD screen to the first column (0) of the first row (0).

• **Line19:** Prints the text "HELLO SBTU" on the first row of the LCD screen.

• **Line21:** Sets the cursor of the LCD screen to the first column (0) of the second row (1).

• **Line22:** Prints the text "GROUP 4" on the second row of the LCD screen.

• **Line23:** Makes the program wait for 3000 milliseconds (3 seconds). During this time, the text "HELLO SBTU GROUP 4" remains on the screen.

• **Line24:** Clears the LCD screen, erasing all text on the screen.

metin, ekran görüntüsü, yazı tipi içeren bir resim

Yapay zeka tarafından oluşturulan içerik yanlış olabilir.**Function (Continuously Running Loop):**

• **Line26:** This function runs repeatedly after the setup() function is completed.

• **Line29:** Reads the ambient temperature in Celsius from the MLX90614 sensor and assigns this value to the temp variable. As indicated in the code, this line can be commented out for testing purposes ("comment this line if you want to test").

• **Line30:**Prints the text "MODULE PROJECT" to the serial monitor.

• **Line31:** Prints the text "Temp: " to the serial monitor.

• **Line32:**Prints the temperature value stored in the temp variable to the serial monitor.

• **Line33:** Prints " °C" to the serial monitor and moves the cursor to the next line (thanks to the println function).

• **Line34:** Sets the LCD screen's cursor to the first column (0) of the first row (0).

• **Line35:** Prints "MODULE PROJECT" to the first row of the LCD.

• **Line36:** Sets the LCD screen's cursor to the first column (0) of the second row (1).

• **Line37:** Prints "Temp: " to the second row of the LCD.

• **Line38:** Sets the LCD screen's cursor to the sixth column (6) of the second row (1).

• **Line39:** Prints the temperature value stored in the temp variable to the second row of the LCD.

• **Line40:** Prints the degree symbol (°) to the LCD screen. (char)223 indicates that the character with ASCII code 223 is the degree symbol.

• **Line41:** Sets the LCD screen's cursor to the twelfth column (12) of the second row (1).

• **Line42:** Prints the character "C" (for Celsius) to the second row of the LCD screen.

• **Line43:** Makes the program wait for 1000 milliseconds (1 second). This ensures that temperature readings and screen updates occur every second.

**ROOM TEMPERATURE ACCORDING TO SCIENTIFIC AND INTERNATION STANDARDS**

|  |  |
| --- | --- |
| **Organisation** | **Room Temperature** |
| IUPAC (International Union of Pure and Applied Chemistry) | 25 °C |
| ISO 554 (International Standards Organization) | 23 °C ± 2 °C |
| ANSI / ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) | 20 – 24 °C |
| TS 825 (Turkish Standard – Thermal Insulation Rules) | 20 °C |

**Comparison of Measured Values ​​and Scientific Values**

**metin, elektronik donanım, kablo, elektronik mühendisliği içeren bir resim

Yapay zeka tarafından oluşturulan içerik yanlış olabilir.**

***Figure 1.12***

As a result, approximately correct and precise temperature measurements are obtained within a certain range, signal conditioning increases reliability and provides a user-friendly interface. As seen in ***Figure 1.12***, the measured value at room temperature was found to be 25.47 °C. The percentage error rate for this value is found using the following formula:

• Error rate according to **IUPAC** = 1.88%

• Error rate according to **ISO 554** = 10.73%

• Error rate according to **ANSI / ASHRAE** = 15.77%

• Error rate according to **TS 825** = 27.35%

**FUTURE TECHNOLOGIES AND DEVELOPMENT AREAS**

**The Evolution and Upcoming Applications of Non-Contact Temperature Measurement Systems**

This project, which is based on the MLX90614 infrared temperature sensor integrated with an Arduino Uno microcontroller, represents a fundamental non-contact temperature sensing system commonly used today in fields such as healthcare, environmental monitoring, and automation. These systems are expected to evolve significantly in the future, and the following trends outline the most prominent development directions:

• **AI and Machine Learning-Supported Data Processing**

Rather than simply displaying temperature values, future systems will increasingly analyze and interpret sensor data using artificial intelligence.

For example:

* Predictive maintenance algorithms may be triggered by abnormal thermal trends,
* Machine learning models can classify patterns and detect anomalies,
* Automated alerts can be issued based on dynamic environmental behavior.

• **Our Future Technologies and Development Areas**

**1.Introduction**

Temperature-sensitive food products such as meat and dairy are highly susceptible to spoilage due to deviations in storage conditions. This project presents a novel approach using an infrared (IR) temperature sensor integrated into a flexible laminate format. The goal is to embed this smart sensor system directly into the packaging of perishable items, enabling real-time monitoring and status indication of spoilage risk.

# **2. System Architecture**

The system consists of the following primary modules arranged in a functional sequence:

***metin, ekran görüntüsü, yazı tipi, cebir içeren bir resim

Yapay zeka tarafından oluşturulan içerik yanlış olabilir.***

***Figure 1.13***

# **3. Working Principle**

The MLX90614 infrared sensor is placed in direct alignment with the internal surface of the food packaging. It continuously measures surface temperature. When the measured value exceeds a critical threshold (e.g., 4°C), the microcontroller processes this data and triggers either a visual signal (such as an RGB LED) or a wireless communication alert via NFC or Bluetooth modules.

# **4. Hardware Components**

|  |  |
| --- | --- |
| **Component** | **Function and Description** |
| MLX90614 | Non-contact IR temperature sensor with high precision. |
| ATtiny85 / ESP32-C3 | Ultra-compact, low-power microcontroller. |
| Flexible PCB | Flexible printed circuit board for lamination integration. |
| 3V Li-Po Battery / Flexible Coin Cell | Low-profile power source suitable for embedded packaging. |
| RGB LED or E-Ink | Visual indicator for spoilage status (safe/spoiled). |
| Bluetooth/NFC Module | Optional wireless communication for user alerts or mobile scanning. |

# **5. Future Technological Developments**

- Implementation of blockchain-based cold chain tracking for ensuring transparency and accountability.  
- Utilization of AI algorithms to predict spoilage based on historical and real-time temperature trends.  
- Integration of gas, pH, or humidity sensors for multi-parameter spoilage detection.  
- Development of smart packaging with QR or NFC tags for consumer access to temperature history.

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