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DESIGN AND DEVELOPMENT OF AN EMBEDDED TRAINER KIT FOR STEM EDUCATION

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***ABSTRACT*: Nowadays our world is filled with embedded systems and the demand for engineers in this field is growing rapidly. To prepare individuals for careers in this industry, STEM education plays a role. However, teaching embedded systems can be challenging as it requires students to have a foundation in electronics, hardware, and software. One effective solution to tackle this issue is by providing students with hands-on learning opportunities through the use of embedded trainer kits. In this article, we will discuss the planning and development of an embedded trainer kit designed specifically for STEM education. This kit is based on a microcontroller board. Includes sensors, actuators, and other components that enable students to create and program their own embedded systems. Additionally, the package also provides software development tools to support their learning journey.**

I. INTRODUCTION

In today's changing technology landscape, it is crucial to prioritize STEM education as it plays a role in nurturing innovative problem-solving skills and critical thinking among children. Building a foundation in these subjects requires hands-on experience. One effective way to achieve this is by utilizing specialized Embedded Trainer Kits designed specifically for STEM education.

The objective of this project is to introduce an Embedded Trainer Kit that empowers educators to provide students with an interactive learning experience, in the field of embedded systems and related topics. This kit will serve as a resource empowering the next generation of engineers and technicians equipping them with the confidence to tackle real-world challenges.

The kit offers a range of STEM-related modules and activities that aim to motivate students to actively participate in learning, exploration, and problem-solving. Through hands-on experience, with programming languages, microcontrollers, sensors, and actuators students will develop skills in embedded systems design and development. The kit encourages finished projects to nurture students' originality and creativity by allowing them to explore their ideas. Additionally, it promotes collaboration and teamwork by providing opportunities for group activities during project work.

The modular design of the kit includes parts such as microcontrollers, sensors, displays, and communication modules. This design flexibility allows students to create projects based on their interests. Moreover, the user-friendly nature of the kit makes it accessible to kids of all ages, educational backgrounds, and technical proficiency levels.

To support instructors in integrating the curriculum into their lesson plans a comprehensive curriculum will be provided along with the tools. The emphasis will be on project-based learning to encourage students to conceptualize ideas and complete projects that showcase applications of embedded systems.

In addition to the kit, there will also be a resource that provides additional information, classes, and a platform for teachers and students to engage in discussions and ask questions.

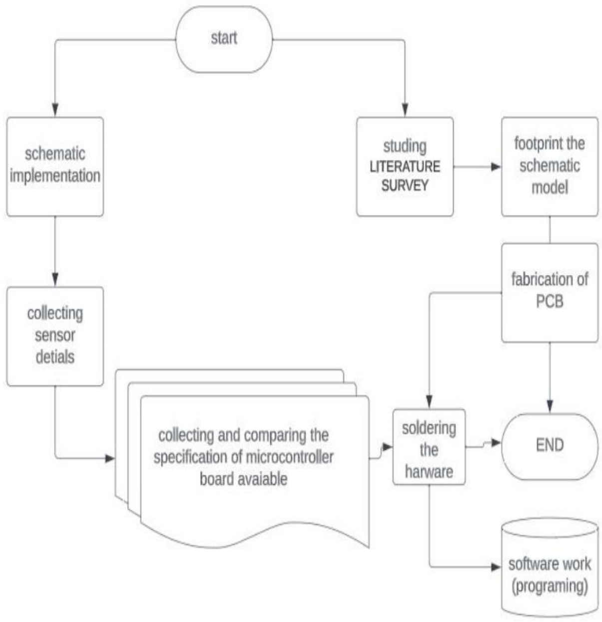

Fig 1: Flowchart of Work flow

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II. METHODS AND MATERIALS

The sensor recognizes its physical surroundings and gathers information from them. This analog signal is processed by the sensor, which then transmits it to an ADC to be converted to a digital signal and relayed to the controller. The display screen, which shows the digital value of the sensor and its function, receives the received digital data from the ADC from the controller. The list of sensors used for the creation of the sensor demonstration trainer kit is presented in Table No. 1 below. The sensor demonstration kit uses about 20 sensors, as shown in the table, which were chosen based on their nature, use, and educational goals. The domain and kind of sensors, as well as the technical nomenclature of the sensors, are specifically described. The table also includes the sensor's working range, which informs us of the highest value the sensor is capable of reporting while sensing any physical input from the environment.

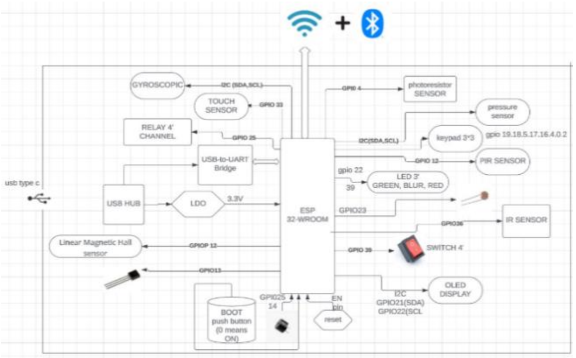

Fig 2: Block Diagram

III. LIST OF SENSORS AND THEIR SPECIFICATIONS

IR SENSOR:

An IR sensor is a device that detects and measures infrared radiation in its surrounding environment. It operates by using the principles of infrared spectroscopy, where it senses the radiation emitted, reflected, or absorbed by objects. IR sensors are widely used in various applications due to their versatility and sensitivity to heat radiation. Below are the specifications and common uses of IR sensors:

SPECIFICATIONS:

1. Operating Wavelength: IR sensors typically operate in the infrared spectrum, which ranges from about 700 nanometers (near-infrared) to 1 millimeter (far-infrared). The specific wavelength range depends on the sensor's intended application.
2. Detection Range: The detection range of an IR sensor varies depending on its type. Some sensors can detect IR radiation in proximity, while others are designed for long-range detection.
3. Response Time: IR sensors are known for their fast response times, making them suitable for applications that require real-time detection.
4. Resolution: The resolution of an IR sensor determines its ability to distinguish between different levels of infrared radiation. Higher-resolution sensors provide more accurate measurements.
5. Sensitivity: Sensitivity refers to the ability of the sensor to detect small changes in infrared radiation. Higher sensitivity allows the sensor to detect subtle variations in temperature or radiation levels.
6. Operating Temperature Range: IR sensors are designed to operate in specific temperature ranges. Some are optimized for low-temperature applications, while others can withstand high-temperature environments.

TABLE I IR SENSOR SPECIFICATION

VCC	3.3 to 5V DC Supply Input
GND	Ground Input
OUT	The output that goes low when an obstacle is in range
Power LED	Illuminates when power is applied
Obstacle LED	Illuminates when power is applied
IR Emitter	Infrared emitter LED
IR Receiver	The infrared receiver receives a signal transmitted by an Infrared emitter.

IR SENSOR RECEIVER:

An IR transmitter's radiation is picked up by infrared receivers or infrared sensors. Photodiodes and phototransistors are the two common types of IR receivers. As opposed to regular photodiodes, infrared photodiodes only pick up on infrared radiation.

SPECIFICATIONS:

1. Operating Wavelength: IR receivers are designed to operate in specific wavelength ranges. Commonly used wavelengths for consumer electronics applications are around 850 to 950 nanometers (nm).
2. Reception Angle: IR receivers typically have a specified reception angle, which determines the range of angles over which they can effectively receive IR signals. Common angles include 30, 45, or 90 degrees, but this can vary.
3. Supply Voltage: IR receiver modules have specific voltage requirements. Common voltages include 3.3V and 5V. The voltage supply must match the receiver's specifications for proper operation.
4. Output Signal: IR receiver modules typically have open-collector or open-drain outputs. This means they don't actively drive the output high; instead, they pull it low when receiving a valid IR signal. This output configuration requires an external pull-up resistor.
5. Output Voltage Levels: The output voltage levels of an IR receiver are crucial for interfacing with microcontrollers or other digital logic devices. Typically, the output is pulled low (near 0V) when a signal is detected and high (usually close to the supply voltage) when no signal is present.
6. Data Format: IR receivers may support various data formats, depending on the communication protocol they are designed for. Common formats include NEC, Sony SIRC, and RC-5, among others.
7. Operating Temperature Range: The operating temperature range specifies the temperatures within which the IR receiver can reliably operate. It is essential to consider this when selecting a receiver for specific applications.

Response Time: IR receivers should have a fast response time to detect and process incoming IR signals accurately. Response times are typically measured in microseconds.

TABLE II IR (RECEIVER) SPECIFICATION

Item Weight	100 g(Grams)
Working voltage	3.3 to 5V DC
Operating voltage	3.3V: ~23 mA, to 5V: ~43 mA
Detection range	2cm – 30cm (Adjustable using potentiometer
Active output level	The output is "0" (Low) when an obstacle is detected

PRESSURE SENSOR:

A pressure sensor is a device that measures pressure and converts it into an electronic signal, the strength of which is based on the pressure being applied. TE Connectivity (TE) develops and produces pressure sensors from the sensing element through system packaging for use in difficult circumstances.

SPECIFICATIONS:

1. Pressure Range: Pressure sensors are designed to measure pressure within specific ranges. Common units of measurement include psi (pounds per square inch), bar, pascal (Pa), and others. The range should match the expected pressure levels in the application.
2. Accuracy: The accuracy of a pressure sensor indicates how closely it measures the actual pressure. It is typically specified as a percentage of the full-scale pressure range.
3. Resolution: Resolution refers to the smallest pressure change the sensor can detect and display. It is expressed in units such as bar or Pa and is essential for applications requiring high precision.
4. Output Type: Pressure sensors can have analog (e.g., voltage or current) or digital outputs (e.g., I2C or SPI). The choice depends on the application and the compatibility with the receiving system.
5. Response Time: The response time of a pressure sensor is the time it takes to provide a stable output after a change in pressure. Faster response times are crucial for dynamic applications.
6. Temperature Range: Pressure sensors have specified operating temperature ranges. Make sure the sensor can operate in the expected environmental conditions.
7. Pressure Medium: Some sensors are designed for specific pressure mediums (liquids or gasses). Ensure compatibility with the medium in your application.

TEMPERATURE SENSOR:

Temperature sensors are tools that monitor temperature and detect cold and heat, converting the information into an electrical output. Everyday objects like residential water heaters, thermometers, refrigerators, and microwaves all use temperature sensors. Another way to think of a temperature sensor is as a straightforward device that monitors how cold or hot something is and then turns that measurement into a readable unit. To detect the temperature of boreholes, dirt, massive concrete dams, or structures, specialized temperature sensors are employed.

SPECIFICATIONS:

1. Temperature Range: The temperature range is the range of temperatures over which the sensor can accurately measure temperature. It is essential to choose a sensor with a range that encompasses the temperatures of interest in your application.
2. Accuracy: Accuracy indicates how closely the sensor's measurements align with the true temperature. It is usually specified as a percentage of the full-scale range (e.g., ±0.1% of the full-scale temperature range). Higher accuracy is essential for precision applications.
3. Resolution: Resolution refers to the smallest temperature difference that the sensor can detect and report. It is typically specified in degrees Celsius (°C) or Fahrenheit (°F) and is crucial for applications requiring fine temperature control or measurement precision.
4. Response Time: The response time is the time it takes for the sensor to detect and report a temperature change in its environment. Faster response times are necessary for applications where rapid temperature fluctuations occur.
5. Operating Temperature Range: This range specifies the temperatures within which the sensor can reliably operate. It is crucial to ensure that the sensor can withstand the environmental conditions of your application.
6. Output Type: Temperature sensors can have analog outputs (e.g., voltage or current), digital outputs (e.g., I2C or SPI), or a simple resistance change (e.g., thermistors). The choice depends on the compatibility with your measurement system and application requirements.

PIR SENSOR:

An electronic sensor called a passive infrared sensor (PIR sensor) monitors the infrared (IR) light that objects in its range of view emit. Their primary application is in PIR-based motion detectors. Security alarms and automatic lighting systems frequently employ PIR sensors that can identify general movement but cannot identify the person or object that moved. An imaging infrared sensor is needed for it.

SPECIFICATIONS:

1. Detection Range: The detection range of a PIR sensor is the maximum distance at which it can detect motion. It is usually specified in meters or feet. The range can vary depending on the specific PIR sensor model.
2. Field of View (FOV): The FOV of a PIR sensor defines the area it can monitor for motion. It is usually described in degrees, and the shape of the detection area can vary (e.g., circular or rectangular). Some PIR sensors may have multiple sensing zones for increased coverage.
3. Sensing Technology: PIR sensors use pyroelectric materials to detect changes in infrared radiation. The sensitivity of the sensor can often be adjusted to account for different levels of motion.

4. Detection Pattern: PIR sensors have a detection pattern that describes how they respond to motion within their FOV. This pattern can vary, with some sensors providing 360-degree coverage and others offering specific angles of detection.
5. Time Delay: PIR sensors often include a time delay setting, which determines how long the sensor remains active after detecting motion. This delay can range from a few seconds to several minutes.
6. Trigger Modes: Some PIR sensors offer different trigger modes, such as single-shot (detect motion once and then reset) or re-triggerable (remain active as long as motion is detected).
7. Output Type: PIR sensors typically provide digital outputs, such as high or low logic levels, to indicate motion detection. These outputs are compatible with microcontrollers and other digital devices.
8. Operating Voltage: PIR sensors operate within specific voltage ranges. Common voltages include 3.3V and 5V. Ensure that the sensor is compatible with your power supply.
9. Power Consumption: PIR sensors are designed to be energy-efficient, but their power consumption should be considered, especially in battery-powered applications

TABLE III PIR SENSOR SPECIFICATION

Voltage	4.8 V – 20 V
Current (idle)	<50 µA
Logic output	3.3 V / 0 V
Delay time	0.3 s – 200 s, custom up to 10 min
Lock time	2.5 s (default)
Trigger	repeat: L = disable, H = enable
Sensing range	<120 °, within 7 m
Temperature	– 15 ~ +70 °C

TOUCH SENSOR:

Electronic sensors with touch sensitivity are called touch sensors. When touched, they behave like switches. Lamps, mobile touch screens, and other devices use these sensors. An easy-to-use user interface is provided via touch sensors. A second name for touch sensors is tactile sensors. They are inexpensive, easy to design, and widely made. These sensors are rapidly replacing mechanical switches because of technological advancements. There are two different kinds of touch sensors: capacitive sensors and resistive sensors. In portable electronics, capacitive sensors are used to measure capacitance.

SPECIFICATIONS:

1. Sensing Principle: Touch sensors use various principles to detect touch, including capacitive sensing, resistive sensing, and surface acoustic wave (SAW) technology. The sensing principle affects the sensor's performance and capabilities.
2. Sensitivity: Sensitivity refers to how easily the touch sensor can detect a touch or proximity of a conductive object. Adjustable sensitivity levels may be available on some touch sensors to accommodate different touch conditions.
3. Touch Area: The touch area is the region of the sensor's surface that can detect touch. It can vary in size, from small buttons to large touchpads or screens.
4. Multi-Touch Support: Some touch sensors support multi-touch, allowing them to detect and differentiate between multiple simultaneous touches. This feature is essential for applications like smartphones and tablets.
5. Operating Voltage: Touch sensors have specific voltage requirements for operation. Common voltage levels include 3.3V and 5V. Ensure compatibility with your power supply.
6. Interface: Touch sensors typically provide digital or analog outputs that indicate touch events. Digital outputs are often used for simple touch or no-touch detection, while analog outputs can provide information about the touch intensity or position.
7. Response Time: Response time is the time it takes for the touch sensor to detect a touch and generate a corresponding output signal. Faster response times are critical for applications requiring real-time interaction.

HALL SENSOR:

Touch sensors are used to detect the presence or touch of a conductive object (such as a finger), also known as touch-sensitive switches or capacitive touch sensors. Common uses for these sensors include consumer electronics, industrial control systems, and human-machine interfaces.

SPECIFICATIONS:

1. Sensing Principle: Touch sensors use various principles to detect touch, including capacitive sensing, resistive sensing, and surface acoustic wave (SAW) technology. The sensing principle affects the sensor's performance and capabilities.
2. Sensitivity: Sensitivity refers to how easily the touch sensor can detect a touch or proximity of a conductive object. Adjustable sensitivity levels may be available on some touch sensors to accommodate different touch conditions.
3. Activation Force: This parameter specifies the minimum force or pressure required to activate the touch sensor. Some touch sensors have a low activation force, making them suitable for sensitive touch applications, while others require a more deliberate touch.
4. Touch Area: The touch area is the region of the sensor's surface that can detect touch. It can vary in size, from small buttons to large touchpads or screens
5. Multi-Touch Support: Some touch sensors support multi-touch, allowing them to detect and differentiate between multiple simultaneous touches. This feature is essential for applications like smartphones and tablets
6. Operating Voltage: Touch sensors have specific voltage requirements for operation. Common voltage levels include 3.3V and 5V. Ensure compatibility with your power supply.
7. Interface: Touch sensors typically provide digital or analog outputs that indicate touch events. Digital outputs are often used for simple touch or no-touch detection, while analog outputs can provide information about the touch intensity or position.

8. Response Time: Response time is the time it takes for the touch sensor to detect a touch and generate a corresponding output signal. Faster response times are critical for applications requiring real-time interaction.
9. Environmental Conditions: Consider the operating temperature range and environmental conditions, such as humidity and moisture resistance, to ensure the touch sensor can perform reliably in your application.
10. Integration: Touch sensors come in various form factors, including discrete buttons, touchpads, and touchscreens. Choose the form factor that best fits your application's design requirements.

GYRO SENSOR:

Gyro sensors, also referred to as angular velocity sensors, can recognize shifts in rotation angle per unit of time. This makes it possible to detect things like vibration, rotation angle, and rotation direction. Smartphones, digital cameras, game consoles, automobile navigation systems, robotics, industrial equipment, and other devices where functionality like vibration detection, camera shake correction, and attitude control are required all use gyro sensors.

SPECIFICATIONS:

1. Sensing Technology: Gyro sensors can use different technologies, including MEMS (Micro-Electro-Mechanical Systems): These gyro sensors are based on microscale mechanical structures and are widely used due to their compact size and low power consumption.
2. Angular Velocity Range: This specification defines the range of angular velocities (rotational speeds) that the gyro sensor can accurately measure. It is typically specified in degrees per second (°/s) or radians per second (rad/s).
3. Sensitivity: Sensitivity refers to the smallest detectable change in angular velocity. It is usually specified in millivolts per degree per second (mV/°/s) or millivolts per radian per second (mV/rad/s).
4. Resolution: Resolution indicates the smallest change in angular velocity that the sensor can measure. It is typically specified in degrees per second or radians per second.
5. Noise Level: Noise level represents the unwanted electrical or mechanical interference in the sensor's output signal, affecting the accuracy of angular velocity measurements. Lower noise levels are preferable for high-precision applications.
6. Bias Stability: Bias stability indicates the sensor's ability to provide consistent measurements over time, even in the absence of rotation. It is specified in degrees per hour (°/hr) or radians per hour (rad/hr).
7. Drift: Gyro sensors can exhibit drift, which is a slow and gradual change in their output over time. Drift can be specified in degrees per hour or radians per hour.
8. Bandwidth: Bandwidth refers to the frequency range within which the gyro sensor can accurately measure angular velocity. It is typically specified in hertz (Hz).
9. Output Type: Gyro sensors provide analog or digital output signals. Analog output sensors produce continuous voltage signals proportional to the angular velocity, while digital output sensors provide discrete digital values.
10. Operating Temperature Range: This specification defines the range of temperatures within which the gyro sensor can operate reliably. It is essential to ensure that the sensor can withstand the environmental conditions of the application.

PHOTORESISTOR:

A photoresistor, often referred to as a photocell, light-dependent resistor, LDR, or photo-conductive cell, is a passive component that lowers resistance when brightness (light) is received on the component's sensitive surface. A photoresistor is said to exhibit photoconductivity when the resistance of the device lowers as the intensity of the incident light increases. In light-sensitive detector circuits as well as light- and dark-activated switching circuits, a photoresistor can be used in the place of a resistance semiconductor. A photoresistor's resistance in the dark can reach several megaohms (M), yet in the light, it can drop to only a few hundred ohms. When photons are absorbed by a semiconductor in a photoresistor, bound electrons receive enough energy to jump into the conduction if the incident light is above a specific frequency.

SPECIFICATIONS:

1. Resistance Variation: Photoresistors are characterized by their resistance variation with changing light intensity. When exposed to light, their resistance decreases, and when in darkness, their resistance increases. The resistance change can be significant, making them useful for detecting light levels.
2. Sensitivity: Sensitivity refers to how responsive the photoresistor is to changes in light intensity. It is typically expressed as resistance values in both well-lit and dark conditions. Higher sensitivity photoresistors exhibit more significant resistance variations.
3. Dark Resistance: Dark resistance is the resistance of the photoresistor when it is not exposed to any light. This parameter is specified in ohms (Ω) and is essential for understanding the sensor's behavior in low-light conditions.
4. Light Resistance: Light resistance is the resistance of the photoresistor when exposed to a specific standard illumination level. It is also specified in ohms (Ω) and is used as a reference point for calibration.
5. Response Time: Response time is the time it takes for the photoresistor to react to changes in light intensity. It can vary depending on the specific sensor and its construction.
6. Operating Voltage: Photoresistors typically operate at low voltages, commonly 3.3V or 5V. It is essential to ensure that the sensor voltage is compatible with your application's requirements.
7. Temperature Dependence: Photoresistor sensors can be temperature-sensitive, and their resistance may change with temperature variations. Some models are designed to compensate for temperature effects.
8. Package Type: Photoresistors come in various package types, including through-hole and surface-mount packages. The package type can affect the ease of integration into your circuit.
9. Mounting: Consider the physical design and mounting options of the photoresistor sensor, especially if it needs to be securely placed or embedded in an application.

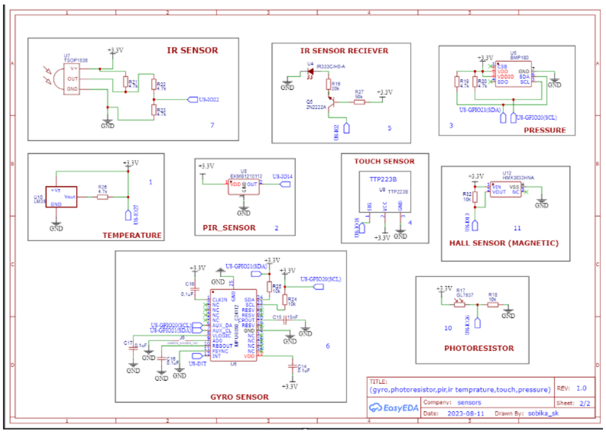

Fig 3: Sensor schematic

IV. CHALLENGES IN SENSOR KIT CONSTRUCTION:

The sensor kit's main role was to show information about the sensor, including its name, function, and output value. Overall, the sensor accomplishes its goal and provides us with a thorough output. Eight sensors in all, including digital and analog kinds, were employed, and they successfully interfaced with the ESP 32 microcontroller. The ESP 32 serial monitor and the OLED Display both clearly showed the display when the OLED display unit's integration was finished successfully. The aesthetics were taken into account throughout the sensor kit's construction. Nevertheless, there were difficulties encountered in the construction of the sensor kit. Since most sensors were analog, it was challenging to convert. A crucial first step in enhancing STEM learning possibilities is designing and producing an embedded training kit. This kit will help kids develop their problem-solving skills and creativity, laying the foundation for a more hopeful future in technology and engineering. By combining academic understanding with practical application, it achieves this. By working together, educators, developers, and the educational community will create the next generation of competent specialists and leaders in the STEM fields.

The development of an embedded trainer kit for STEM (Science, Technology, Engineering, and Mathematics) education is a revolutionary step toward enhancing the educational experience for students of all ages in the ever-evolving educational environment. This ambitious project gave students a flexible and interactive tool to explore the fascinating world of STEM courses to bridge the knowledge gap between theory and application. The embedded trainer kit is a remarkable example of innovation that is paving the way for a better future for education, as is evident from a careful evaluation of this project. This complete training package has through a thorough planning and research process, as well as a dedicated collaborative approach from conception to implementation. All of these efforts have resulted in a multifaceted educational tool that not only engages youngsters but also equips them with the skills and knowledge they need to be successful in STEM careers. Because it touches on so many important aspects of modern education, the significance of this accomplishment cannot be overstated. The integrated trainer kit has entirely redesigned the learning process by giving students a practical platform on which to investigate the subtleties of STEM disciplines. Deep learning is encouraged and students' interest in these disciplines is piqued by offering them the ability to interact with, handle, and play with real-world applications. One of this kit's most remarkable features is its adaptability to various academic levels and STEM subjects.

We utilized the Easy EDA Tool, a web-based platform designed for creating circuit diagrams and PCB footprints, to generate a schematic. In this schematic, we integrated a variety of sensors and to enhance the practical learning experience, we also incorporated additional components such as a switch, OLED display, LED, and keypad. This comprehensive setup allows students to gain hands-on knowledge and a deeper insight into the world of sensors and microcontrollers (Esp. 32).

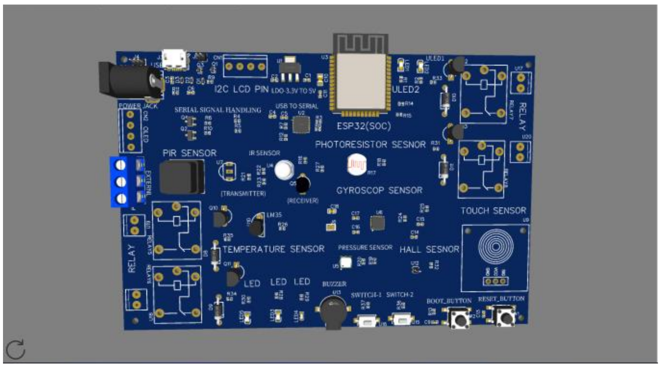

Fig 4: PCB (3D-Model)

V. CONCLUSION

The embedded trainer kit is a versatile tool that both instructors and students can use, whether it's in primary schools to engage young minds or in higher education to promote cutting-edge research and experimentation. By enabling students to design, create, and program their own embedded systems, this kit promotes creativity and problem-solving skills. It inspires them with the possibility that they could be the architects of the future, using STEM to develop solutions to some of the most pressing issues the world is currently facing. Because accessibility is so important in education, our program has made an effort to keep costs cheap and content simple to obtain. By ensuring that STEM education reaches a larger audience, we can foster diversity in these fields and work to remove racial and economic barriers. Instead of being a singular achievement, the integrated training kit signifies a sustained commitment to the improvement of STEM education. To be relevant in the quickly changing technological landscape, the kit's capabilities must be continually updated and expanded to include the newest scientific discoveries and educational innovations.

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