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Design And Implementation of a Cost-Effective GSM-Based Security Alert System

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Abstract- ***Security challenges such as burglary, fire outbreaks and gas leakages continue to pose a great risk to lives and properties. In recent times, modern gadgets are being developed to address these security concerns. However, many of these modern security devices are internet dependent, expensive and not readily available. Thus, limiting their reliability and usage in developing countries and areas with poor internet connectivity. This paper presents the design and implementation of a cost-effective GSM-based security alert system that provides real-time notifications using the Global System for Mobile Communications (GSM) leveraging on the extensive cellular network coverage to ensure reliable communication in remote and urban areas. The system was implemented such that a microcontroller integrated with multiple sensors to detect intrusion, flame and gas respectively, upon detection of any abnormality activates a local alarm and transmits Short Message Service (SMS) alerts to designated users via a GSM module. To ensure its continuous operation, we incorporated rechargeable batteries with the regulated mains power module to enable uninterrupted power supply. Performance evaluation carried out show that the system responds promptly to security threats and delivers alerts reliably within few seconds. Overall, the system is simple, effective, affordable, and easy to deploy, making it suitable for residential areas, offices, and institutions, especially in remote areas where internet-based security solutions may be unreliable.***

Keywords: Security Alert System, Fire Detection, Gas leakage, Intrusion Detection, GSM Module

I. INTRODUCTION

The growing need to protect lives and properties in the face of increasing security threats remain a fundamental concern in human history. In many developing regions, these threats are further compounded by challenges such as unreliable power supply, limited access to advanced security solutions, and slow emergency response systems. Early security systems relied basically on physical and mechanical measures which offered limited response capabilities. While these traditional methods provided basic protection, they were prone to human error, and incapable of providing real-time alerts or remote monitoring [1]. Hence, the improvement in the existing security systems and solutions to address these limitations is actively being explored.

Recent advancement in embedded systems and wireless communication technologies have significantly transformed modern security systems facilitating the development of intelligent, low-cost, and reliable solutions for security monitoring, automation, and remote alert systems. Among these wireless technologies is the Global System for Mobile Communications (GSM) that enable prompt SMS notifications to users irrespective of their locations. [2]. The GSM-based security alert systems demonstrate major improvement over the traditional security approaches.

Our designed security system architecture was built around sensing (sensors), communication (SIM module) and Alert units (Buzzer, display unit, mobile Phone), having the Arduino microcontroller, as the central processing unit responsible for sensor data acquisition, logical decision making, and coordination of system operations. [3]. The sensors form the primary threat-detection components and the deployment of multiple sensors within a single system improved the detection accuracy [4]. The communication unit is basically the SIM-enabled GSM module that establishes communication with the users' phone via the Attention (AT) commands generated from the microcontroller. While the alert unit comprises of the Buzzer that provides audible alert, the LCD unit for visual display of the threat status and the mobile phone that issue SMS notification.

Good number of GSM-based security systems have been implemented and discussed in the scholarly literature [5][6][7], but few addressed the challenge of maintaining continuous operation critical for security solutions and operations. This project adopts a hybrid power architecture that integrates both grid supply and battery backup alongside a multi-sensor detection framework. This design ensures uninterrupted security monitoring during power outages while enhancing detection accuracy [8].

In general, the integration of embedded processing, wireless communication, sensing, actuation, and power backup has significantly improved the effectiveness of the implemented security prototype. This work was motivated by the need to provide a cost-effective, locally adaptable security solution that addresses prevalent security challenges such as burglary, fire outbreaks, and gas leakages in residential and business environment considering the limitations of reliable internet access and high cost of imported products in Nigeria.

II. LITERATURE REVIEW

Studies on various developed GSM- based security systems demonstrated the reliability of GSM technology in prompt alert notifications independent of internet connectivity, capability of multi sensor integration, cost effectiveness and ease of deployment.

GSM dependent smart home security system (AIP Conference, 2023)
Khana, G. et al. (2023) developed a GSM-dependent smart home security system that integrated automation with security features. Their design detected gas leaks, fire outbreaks through smoke and temperature sensors, and intrusion events. By providing early warnings, the system aimed to reduce emergency service expenditures through preventive measures [9]

Design and Construction of Additional Security Device for House Door Using Arduino Uno Based on Short Message Service (2021)
Wara, Y.R. and Putri, T.W.O. (2021) focused on the design and construction of an additional security device for house doors using Arduino Uno and a short message service (SMS) module. Their prototype generated early warning notifications via SMS when door tampering was detected. The study successfully achieved its research objectives [10].

GSM and Arduino based Smart Home Safety and Security System (2023)
Manjushree Nayak and Ashish Kumar Dass proposed a GSM and Arduino-based smart home safety and security system. Their system was designed to detect and prevent various household accidents by issuing timely warnings to occupants. It incorporated three sensors, including a PIR sensor, to enhance security coverage and overall home safety [11]

Home Security System Based on Arduino using SMS (2024)
Maswa Y.A et al presented a home security system developed in response to homes being frequently left unattended and vulnerable to theft. The authors implemented an Arduino Uno- based system using an Infrared sensor and a GSM module as an SMS alert information system. The system works by placing sensors at entry points such as doors, and if a threat is detected, it automatically sends an SMS to the homeowner's mobile phone regardless of their location [12].

Digital Keypad Security System Based on Arduino with GSM Module, Alarm, and Temperature Sensor (2022)
This research examined various security systems applications, including traditional locks, RFID tag-based door locks, gesture-based locks, and GSM/OTP-based technologies. The study highlighted the pros and cons of each locking mechanism and their underlying technologies. The authors propose a cost-effective door lock system that addresses the prevailing pandemic situation by incorporating a contact-based temperature sensor into the security system demonstrating how Arduino-based security systems can adapt to emerging health concerns [13].

GSM based Security Alarm system (2022)
Halder’s work presents an anti-theft alarm system built with Arduino and PIR sensor, using a GSM module to send SMS alerts to specified mobile

numbers when an intruder is detected. The paper provides valuable context by explaining why such systems are necessary in addressing home robbery, LPG gas leakage accidents, and fire incidents. The methodology section offers practical technical details: PIR sensor used to detect motion required a warm- up time of 20-60 seconds for calibration, and have a typical range of about 6 meters. The study also noted important behavioral characteristics of PIR sensors, such as output fluctuations even during motion detection, which is crucial knowledge for reliable programming [14].

Arduino based gas leakage and temperature monitoring and control system (2020) Boniface, A., Nasir, A.Y., & Hassan, A.M presented a system that addresses the critical problem of gas leakage in industrial sectors, residential premises, and CNG-powered vehicles. The system was made to find LPG leaks with a gas sensor and keep an eye on the temperature of the environment with a temperature sensor. Both sensors are connected to an Arduino microcontroller. The system uses a GSM module to send SMS alerts when the gas concentration goes above a certain level. If the temperature goes above safe levels, it turns on an LED light and a buzzer. A 16x2 LCD shows the current temperature and gas levels in degrees Celsius and PPM, respectively [15].

Pressure measurement algorithm of LPG leakage using MQ6 sensor and GSM SIM900 for smart home (2021).
Suhartono, S., & Suhadi, I. presented research that focused on creating an LPG gas leak detection system for smart homes, addressing the risk of fire and explosion associated with propane and butane gas cylinders. The study developed a pressure measurement algorithm using the MQ6 Gas sensor, which is specifically designed to detect LPG, propane, and butane. The system is connected to an Arduino microcontroller and uses a GSM SIM900A module as an SMS gateway to send alerts when there are leaks. Tests showed that the detector works best when it is 5 cm away from the gas source, and the speed at which it sends notifications depends on the quality of the network. The study offers an algorithmic methodology for gas leak measurement and the practical implementation of SMS notifications [16].

Smoke Indicator Alarms and Gas Sensors (2022)
Ab Aziz, N.N., Sanusi Ikhsan, M.H., Salim, N.N., & Maseji, K. from the University of Tun Hussein Onn, Malaysia presented a smoke and gas sensor system using an Arduino Nano with ATmega328p microcontroller. The system uses an MQ2 gas sensor for smoke detection and a flame sensor for fire detection. When the gas sensor detects smoke levels of 200 or more, an alert appears on the LCD display and an SMS alert is sent to users via GSM module. If the flame sensor detects fire, it also displays an alarm on the LCD and calls the users. The research addresses the limitation that many safety systems only provide local alarms, leaving property owners unaware of emergencies when off-site. This technology helps users improve safety standards by providing rapid response [17].

File security system using GSM module, flame sensor and Arduino (2023)
Sattibabu, D., Srivastava,N., Swetha, T.L., Vishnukanth,T.,& Praveen, K. (2023) worked on an AIP conference paper that presented an automatic fire detection system using a flame sensor connected to an Arduino microcontroller. The system meets the urgent need for early fire detection. Fires can destroy everything in a room in minutes and completely destroy buildings in hours. The suggested system has an alarm and a GSM module that sends alerts to cell phones. The study shows that fires happen a lot because people aren't careful enough in places like gas stations, cracker shops, homes, workplaces and forests. The system is meant to fix problems with emergency response by sending out alerts right away. [18].

2.1 RESEARCH GAPS

The reviewed scholarly literatures indicate significant progress in GSM-based security systems utilising Arduino platforms, incorporating motion, gas, and flame sensors. Nevertheless, extensive solutions have been developed and evaluated under ideal power and internet connectivity scenarios.

The system proposed in this project is specifically designed to address the unique challenges

encountered in developing nations, such as Nigeria, including inconsistent electricity supply and internet availability. A rechargeable battery system, a regulated mains power module, and automatic switching that keeps the system running even when the power goes out has been incorporated in this system. Also, the system uses GSM network coverage in sending text messages instead of the internet, so it works perfectly in rural and semi-urban areas where internet infrastructure is often not available or unreliable.

Further improvement lies in the system's capacity to identify a wider range of potential threats. While some research focuses exclusively on intrusion detection, and others on fire or gas hazards, this particular project integrates motion, flame, and gas sensors into a unified system. whereby, intrusion, fire, and gas leaks can be simultaneously detected. The system's microcontroller controls the decision-making process, interpreting all sensor data and triggering both SMS alerts and a buzzer sound. This design ensures that individuals present on-site or off-site receive immediate warnings.

The system was also put together with locally available materials, which cut costs and help develop indigenous technical skills. All of these features make the proposed system a practical, affordable, and strong security solution that is tailored to the needs of developing areas.

III. MATERIALS AND METHODS

Design of an efficient GSM-based security alert system relies on careful selection of components and a clear methodology for their integration and operation. Components were selected based on reliability, responsiveness and energy efficiency.

We provided a comprehensive description of each component’s electrical and operational characteristics as well as the methodology by which they interact to form fully integrated security system. This will enable replication, evaluation and further development of the security system.

3.1 SYSTEM COMPONENT DESCRIPTION

The GSM based security Alert system is made up of both hardware and software components. The hardware components include the Arduino microcontroller, GSM module, Sensors (motion, gas flame), Lithium-Ion Batteries, 16x4 LCD display, Buzzer, DC-DC buck converter, voltage regulator and Relay. While the software component is the Arduino integrated Development Environment(IDE).

- Microcontroller (Arduino ATmega328P):

This serves as the central processing unit of the system. It processes sensor data and controls communication between modules. It operates at 16 MHz clock frequency with digital and analog I/O pins, and Analog-to-Digital conversion (ADC) resolution of 10 bits (0-1023). We used the Arduino Uno microcontroller due to its low power consumption, ease of programming and extensive community support.
The Analog input conversion is given by;

$$V_{sensor} = ADCvalue / 1023 \times V_{ref} \text{ where } V_{ref} = 5V, \quad (1)$$

The microcontroller continuously monitors sensor signals, compares them to predefined thresholds, and activates alarms as well as send SMS alerts via the GSM module.

ATMega328P and Arduino Uno Pin Mapping

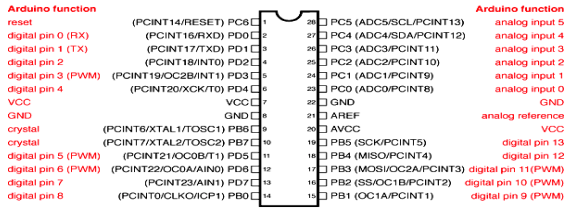

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Figure 1: Pin description of ATMega328P Microcontroller.

- GSM Module (SIM800L):

The SIM800L GSM Module is a compact GSM communication module that enables wireless communication between the security system and the user's mobile phone. The module supports SMS messaging, voice calls, and General Purpose Radio Service (GPRS) communication through a serial interface(UART). It operates in quad-band frequencies (850,900,1800,1900 MHz) GSM/GPRS making it suitable for worldwide network compatibility. The microcontroller communicates with the SIM module using AT commands. Examples of such AT commands include;

- To Connect to GPRS: AT+CGATT=1
- To Read signal strength: AT+CSQ
- To Check SIM card presence: AT+CPIN?
- To set SMS Text mode: AT+CMGF=1
- To specify the recipient number: AT+CMGS="+234XXXXXXXXX"

The operational voltage of GSM module is between 3.4- 4.2V and requires voltage regulation between the microcontroller and the module. This was achieved using the DC-DC buck converter.

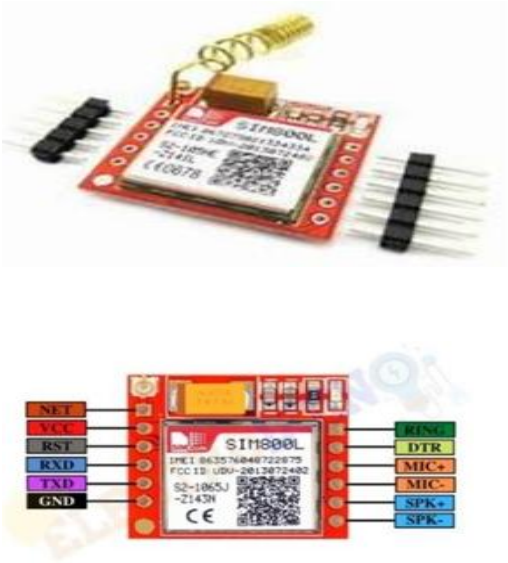

Figure 2: GSM module(800L)

- Sensors

Sensors are electrical components that detect changes in physical or environmental conditions and convert them into electrical signals that can be processed by a control unit. The three sensors used include;

- MQ6-Gas sensor

A semiconductor device used to detect flammable gases such as Butane, methane, propane and Liquefied Petroleum gas (mixture of Propane and Butane). It operates by sensing gas concentration in the surrounding environment and convert the analog signal into an electrical signal. The sensor can detect 300 - 10000ppm LPG gas concentration within a range of 100cm. It has both analog /digital outputs making it easy to interface with systems like Arduino. Due to its high sensitivity, fast response, and low cost, the MQ-6 is widely used in indoor gas leakage detection and safety monitoring applications. For this project, we use 400ppm as the threshold in the sensor calibration.

The sensor resistance (RS) in analog reading can be found using;

$$RS/RL = (V-Vs)/Vs, \text{ where RL is load resistor} \quad (2)$$

While Sensitivity(S) in the presence of the target gas is given by;

$$S= (RG-R0)/R0)=\Delta R/R0 \quad (3)$$

where RG and R0 are the resistance of the sensor in the presence of the target gas and in clean air respectively.

Figure 3: MQ sensor

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- Motion/Passive Infrared (PIR) sensor:

The motion sensor detects motion by sensing the variation in Infrared radiation emitted by warm bodies. It is made of pyroelectric materials that generate a voltage when exposed to changes in infrared radiation.The detection range is usually between 5-7 meters with 120o angle of view. The sensor operates within a voltage range of 4.5V to 20V and produces a digital output signal when motion is detected. When movement is detected within its detection range, the output signal becomes HIGH (approximately 3.3V) and when no motion is detected, the output remains LOW.

The output voltage, Vout is proportional to the rate of change of incident IR radiation.

$$V_{out} \propto \frac{d\Phi_{IR}}{dt} \quad (4)$$

Where ΦIR is the infrared radiation flux
When motion is detected, the microcontroller receives a HIGH signal to trigger local and remote alert.

Figrure 3: Motion Sensor(PIR)

- Infrared Flame Sensor:

The Sensor is used for detecting the presence of fire within 760 – 1100 nm wavelenght. The sensor contains an infrared photodiode that is sensitive to infrared radiation emitted by flames. The operational voltage is between 3.3 – 5V, a detection angle of 60 degrees and detection range of 1-3 meter depending on size of flame.When the sensor detects flame radiation, it produces a digital output signal indicating the presence of fire. If no flame is detected, the sensor output remains low. Photocurrent generated by the flame sensor is proportional to the incident radiation.and it is given by:

$$Iph = R\square \text{ x } Popt \quad (5)$$

Where Iph = Photocurrent, R= Responsivity of the sensor at the wavelenght of the detected radiation and Pout = Incident optical power.

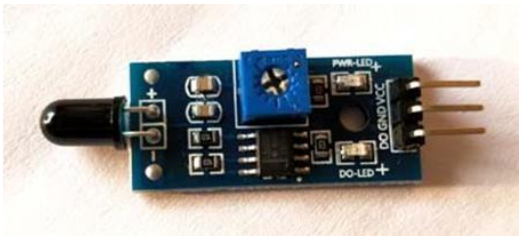

Figure 4: Flame sensor

- The Liquid Crystal Display (LCD)

LCD is commonly used display module in embedded systems for showing text, sensor readings, and system status. In this study, it was used to display the real-time alerts such as “Gas Detected”, “Motion Detected”, “ flame Detected” and the overall system status messages.The LCD is interfaced with Inter-Integrated Circuit (I^2C) to minimise wiring complexity and pin usage.

- Buzzer:

An electro-acoustic device that converts electrical signals into audible sound using the piezoelectric effect. Buzzers are widely used in embedded systems for alarm and notification purposes due to their simplicity, low power consumption, and reliability. In this study, buzzer functions as a real-time local alert mechanism. It complements the GSM module by providing immediate on-site notification before remote alerts (SMS) are delivered. This ensures rapid awareness and response in emergency situations.

- Lithuim-Ion batteries (3.7v):

An essential component for backup power in embedded systems. Its high efficiency, compact size, and reliability make it ideal for continuous operation of the GSM-based security alert systems, particularly in environments prone to power interruptions. The Li-ion batteries (2S)

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was integrated with Battery Charging Module (TP4056) to ensures safe charging and Protection Circuit Module (PCM) to prevent overcharging, deep discharge and short circuit.

- DC–DC buck converter

An electronic component that steps down a higher input voltage to a lower output voltage. It is widely used in embedded systems to provide regulated voltage levels required by sensitive electronic components. In the developed security system, the buck converter was used to convert higher DC voltage (from the regulated power or battery pack) to a stable 4.2V supply required for GSM module.

- Relay:

The relay is used for power switching in embedded security systems. Its ability to isolate low- power control circuits from high-power loads ensures safe and efficient operations. The relay automatically alternate between the main power supply and a backup battery source to ensure uninterrupted system operation during power outages.

- Ardiuno IDE (Software):

The software used in the secuity prototype was developed in the Arduino Integrated Development Environment (IDE). It is an open-source software platform used for writing, compiling, and uploading code to Arduino-compatible microcontrollers. It provides a simple and user-friendly interface, making it suitable for both beginners and advanced program developers in embedded systems design. Its simplicity, combined with powerful libraries and hardware compatibility, makes it an ideal tool for designing and implementing security systems. The control program is usually written in C++ language.

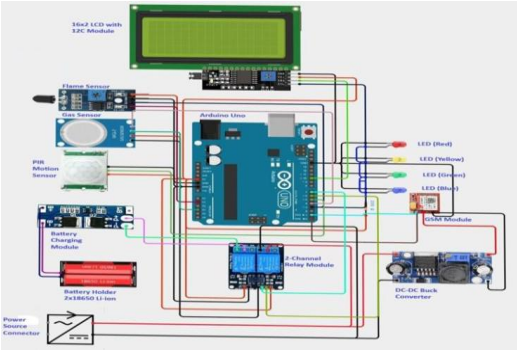

Figure 5: System design

3.2 SYSTEM DESIGN METHOD:

The system design was built around: Sensing unit (motion, flame ,and MQ gas sensors), Processing unit (microcontroller), Communication unit (GSM module),and Localised Alert unit (LCD display, buzzer, and LED indicators).

- Hardware Design

- Sensor Integration: Each sensor is connected to designated input pins on the microcontroller. When thresholds are exceeded (motion, gas leak or flame detected), the microcontroller triggers the appropriate alert.
- GSM Module Configuration: The module communicates with the Arduino via serial UART. When an event is detected, the system sends SMS alert to predefined user phone number.
- Output Indicators: Status LEDs and buzzer are activated in real time to provide local feedback.
- Power Supply: Regulated 12V DC power supply integrated with relay for switching the voltages, 2S lithium battery back up, and Buck converter to provide stable voltage level required by the sensitive components.

- Software integration

- The entire control program was written and uploaded to the microcontroller in the Arduino IDE.
- The main logic includes sensor initialization, continuous monitoring, threshold comparison, and conditional execution of alerts.
- Serial communication between the Arduino and GSM module was established through AT commands to send SMS to mobile phone.

- Operational workflow:

Sensors monitor environmental conditions continuously, on detecting threat, the microcontroller:

- Activates buzzer and LED.
- Displays status on the LCD
- Sends SMS alert via GSM module.

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The system resets and continues monitoring after alerting.

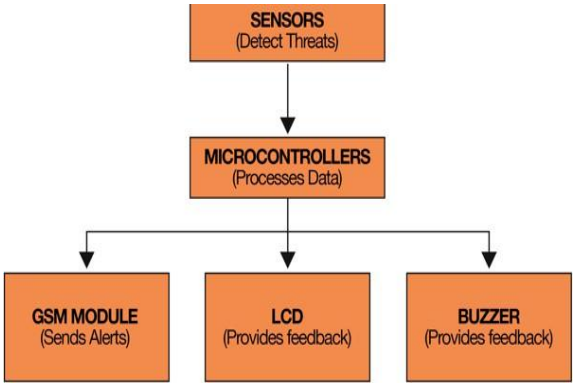

Figure 6: Systems Workflow

IV. RESULTS

The GSM-based security alert system was successfully designed, implemented, and tested under different sensing scenarios;

- Sensor Performance
- Intrusion detection (PIR sensor): Detected human motion within a range of 1– 3 meters.
- Gas detection: Triggered when gas concentration exceeded preset threshold levels.
- Flame detection: Successfully detected fire within a distance of 1–2 meters.

- Alert Transmission
- SMS alerts were sent using the SIM800L GSM Module.
- Average SMS delivery time: 5–15 seconds depending on network conditions.
- Alert success rate: ~95–100% in areas with stable GSM coverage.

- Power Performance
- System operated using mains supply and battery backup + buck converter setup.
- Continuous operation duration: 8–12 hours depending on load and sensor activity.

Figure 7: (a) GSM- Based Security system

(b) Received SMS alert

V. DISCUSSION

The results demonstrate that the GSM-based security alert system is effective for real-time monitoring and remote alerting.

- Reliability of GSM Communication

The use of the SIM800L GSM Module enabled reliable SMS-based communication. However, performance depended heavily on network signal strength. In areas with weak GSM coverage, delays and occasional message failures were observed.

- Sensor Performance

- The PIR sensor performed well for motion detection but was sensitive to environmental factors such as heat and sudden light changes.
- Gas sensors showed high sensitivity but required proper calibration to avoid false alarms.
- Flame sensors provided quick detection, making them suitable for early fire warning systems.

• Power Efficiency

The system demonstrated good power efficiency, making it suitable for remote or off-grid deployment (especially when combined with solar systems).

• Further future improvement

This system aligns with modern IoT-based security solutions and can be enhanced with:

- Cloud integration
- AI-based detection
- Camera modules for visual verification

VI. CONCLUSION

In this study, a GSM-based security alert system was designed and implemented. The designed system is cost-effective, reliable, and provides an efficient solution for real-time security monitoring. It successfully detectected intrusion, fire, and gas leaks and sent alerts remotely via SMS. Despite some limitations such as dependence on GSM network quality and occasional false triggers, the system is suitable for residential and remote security applications. With further improvements such as IoT integration, machine learning-based anomaly detection, and hybrid communication systems, the system can be scaled into a more robust smart security solution.

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