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An IoT-Based Intelligent Geolocation System for Smart Backpack Applications

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ABSTRACT

The loss or theft of personal belongings containing electronic devices and sensitive data is an increasing concern in academic and urban environments. This paper presents the design and experimental validation of an **IoT-based geolocation system** integrated into a smart backpack for on-demand remote tracking. The proposed solution relies on an embedded IoT architecture combining a low-cost microcontroller, a GPS module for outdoor position acquisition, and a GSM communication module enabling long-range data transmission via short message service. An energy-aware design incorporating a rechargeable battery and a solar energy harvesting unit is implemented to enhance system autonomy. The geolocation process is remotely triggered through predefined SMS commands, allowing event-driven localization without continuous Internet connectivity. Experimental evaluations conducted under real-world conditions demonstrate reliable GPS positioning, robust GSM communication, and effective transmission of location information in the form of map links. The results highlight the relevance of the proposed IoT-based system as a practical, low-cost, and energy-efficient solution for portable object tracking and smart personal object applications.

Index Terms: Internet of Things; Smart backpack; Geolocation system; GPS–GSM communication; Portable object tracking; Energy-aware IoT systems

1- Introduction

The increasing integration of embedded sensing technologies, low-power electronics, and wireless communication systems has enabled the development of intelligent solutions for monitoring, tracking, and securing everyday personal objects [1], [2]. Backpacks, widely used in academic and professional contexts to carry electronic devices, documents, and valuable personal belongings, are frequently exposed to public environments, making them particularly vulnerable to loss or theft [3]. This situation motivates the need for reliable, autonomous, and energy-efficient geolocation systems specifically designed for portable personal items.

Geolocation systems for portable objects mainly rely on satellite-based positioning technologies to provide outdoor localization with wide coverage and acceptable accuracy [4], [5]. Satellite navigation systems enable the acquisition of geographic coordinates independently of local infrastructure. When combined with cellular communication technologies, these systems allow long-range transmission of location information without requiring continuous Internet connectivity, offering an effective solution for on-demand localization in loss or theft scenarios [6], [7].

Numerous tracking architectures have been proposed for asset monitoring and mobile object localization [8], [9]. While early solutions primarily focused on vehicle tracking, more recent approaches have extended these concepts to smaller and portable objects, including wearable devices and personal belongings [10], [11].

However, many existing systems address localization accuracy or communication reliability independently, without jointly considering constraints related to hardware miniaturization, system integration, and long-term energy autonomy [12], [13].

Energy autonomy remains a major challenge for embedded geolocation systems intended for prolonged or intermittent operation [14]. Continuous positioning and communication tasks can rapidly deplete battery resources, making energy-efficient system design essential. Several strategies have been explored to reduce power consumption, including low-power hardware architectures, duty cycling techniques, and the use of auxiliary energy sources such as energy harvesting [15], [17]. Despite these efforts, achieving sufficient autonomy while maintaining reliable localization and communication performance remains difficult for systems integrated into everyday portable objects [18].

In this context, this paper presents the design and experimental validation of an intelligent GPS-based geolocation system fully integrated into a smart backpack. The proposed system combines a low-power embedded controller, a satellite positioning module for location acquisition, and a cellular communication module enabling short message service transmission. An autonomous power supply assisted by energy harvesting is implemented to enhance operational autonomy, while remote activation allows localization on demand in loss or theft scenarios. Experimental results obtained under real-world conditions demonstrate the feasibility, reliability, and practical relevance of the proposed solution for portable object tracking applications [19].

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2- TOOLS AND METHODS

2.1 System Components and Technical Specifications

Table 1 summarizes the main hardware and software components used in the proposed geolocation system integrated into the smart backpack. It also highlights the key technical characteristics of each component and their respective roles within the overall system architecture.

TABLE I HARDWARE AND SOFTWARE COMPONENTS

Category	Model / Reference	Main Technical Characteristics	Role in the System
Microcontroller	Arduino Uno R3 (ATmega328P)	8-bit MCU; 16 MHz; 5 V; UART serial interface	System control and data processing
Positioning module	u-blox NEO-6M	GNSS receiver; ±5 m accuracy; 1 Hz update; UART; 3–5 V	Geographic coordinate acquisition
Communication module	SIM800L	Quad-band GSM; SMS support; UART; 3.7–4.2 V	SMS-based data transmission
Battery	Li-ion / Li-Po	3.7 V nominal; 2000–3000 mAh	Primary power supply
Energy source	Polycrystalline solar panel	5–6 V output; up to 200 mA	Battery recharging
Power management	Buck converter / LDO	Regulated 3.3 V / 5 V outputs	Voltage regulation
Communication interface	UART-based serial interface	Configurable baud rate; bidirectional	Serial data exchange
Prototyping support	—	Solderless prototyping platform	Hardware prototyping
Software environment	Arduino IDE	C/C++; USB programming	Firmware development
GPS library	TinyGPSPlus	NMEA parsing; coordinate extraction	GPS data decoding
User interface	Google Maps	Web-based map visualization	Location visualization
Activation method	SMS command	Predefined text message	Remote system activation

2.2 Methods

2.2.1. System block diagram

Fig 1 illustrates the block diagram of the proposed smart backpack geolocation system.

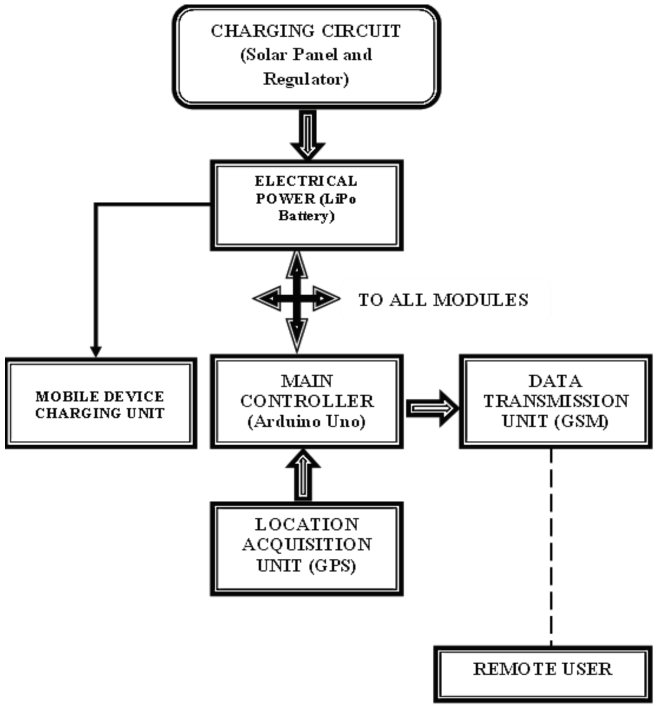

Fig. 1. Diagram block of the proposed smart backpack geolocation system

2.2.3. C++ Programming in Arduino C++

Fig.2 presents a source code excerpt dedicated to geolocation coordinate acquisition, illustrating the use of the TinyGPS Plus library for GPS data decoding and the extraction of position information processed by the microcontroller.

Fig. 2. Diagram portion of the geolocation coordinate acquisition code.

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The second stage of the programming process consists in configuring the SIM800L GSM module as an SMS sender. This step enables the transmission of geolocation information to the remote user through text messages. Fig 3 shows a code excerpt illustrating the configuration of the SIM800L module for SMS transmission, including the initialization commands and the setup of the text message mode.

```
#include <SoftwareSerial.h>
SoftwareSerial mySerial(2, 3);

void setup()
{
  Serial.begin(9600);
  mySerial.begin(9600);
  Serial.println("Initializing...");
  delay(1000);

  mySerial.println("AT");
  updateSerial();

  mySerial.println("AT+CMGF=1");
  updateSerial();
  mySerial.println("AT+CMGS=\"+237694749374\"");
```

Fig. 3. Code excerpt for configuring the SIM800L module as an SMS sender.

The third stage of the programming process focuses on configuring the SIM800L GSM module as an SMS receiver. This step enables the system to receive incoming text messages used to remotely trigger the geolocation process. Fig.4 presents a code excerpt illustrating the configuration of the SIM800L module for SMS reception, including the initialization commands and the setup required to detect and process incoming messages.

```
#include <SoftwareSerial.h>
SoftwareSerial mySerial(2, 3);
void setup()
{
  Serial.begin(9600);
  mySerial.begin(9600);
  Serial.println("Initializing...");
  delay(1000);

  mySerial.println("AT");
  updateSerial();
  mySerial.println("AT+CMGF=1");
  updateSerial();
  mySerial.println("AT+CNMI=1,2,0,0,0");    updateSerial();
}
void loop()
```

Fig. 4. Code excerpt for configuring the SIM800L module as an SMS receiver.

The final stage of the programming process concerns the overall configuration of the geolocation instrument, ensuring proper coordination between the GPS acquisition, GSM communication, and system control functions. Fig. 5 presents a code excerpt illustrating the final configuration of the geolocation instrument, where the different software modules are integrated to enable complete system operation.

```
#include <TinyGPS++.h>
TinyGPSPlus gps;
double latitude, longitude;
#include <SoftwareSerial.h>
SoftwareSerial SIM800L(2, 3);
String response;
int lastStringLength = response.length();
String link;
void setup() {
  Serial.begin(9600);
  Serial.println("GPS Mulai");

  SIM800L.begin(9600);
  SIM800L.println("AT+CMGF=1");
  Serial.println("SIM800L started at 9600");
  delay(1000);
```

Fig. 5. Code excerpt showing the final configuration of the geolocation instrument.

3- RESULTS AND DISCUSSION

3.1 Results of the virtual design of the geolocation device

As illustrated in Fig. 6, the proposed hardware implementation confirms the feasibility of an autonomous embedded geolocation system integrating sensing, processing, and communication functionalities within a compact architecture. The GPS–cellular tracking approach, managed by a low-power embedded controller and supported by an autonomous power supply, enables reliable outdoor localization and robust data transmission, in line with recent advances in IoT-based tracking systems for portable objects [3], [4], [8].

The experimental results demonstrate that the proposed architecture effectively addresses key constraints related to energy efficiency, system integration, and communication reliability, which have been identified as major challenges in existing tracking solutions [12], [14]. Moreover, the overall system behavior and performance are consistent with previously reported smart object and wearable tracking platforms, including backpack-oriented implementations, while providing improved integration and autonomy for real-world usage scenarios [9], [19].

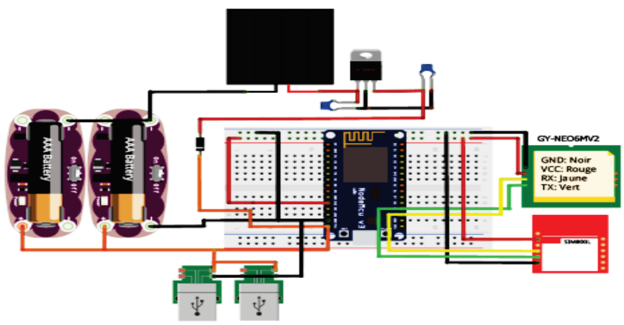

Fig. 6. Virtual design of the geolocation device.

3.2. Geolocation Test Results

As shown in Fig. 7, the experimental test bench demonstrates the practical integration of the proposed geolocation system by

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combining GPS-based position acquisition, cellular communication, and microcontroller-driven data processing within a compact embedded architecture. The wiring configuration validates reliable inter-module communication and stable real-time position tracking, in agreement with low-power IoT tracking system designs reported in recent studies [3], [4].
The observed localization behavior is consistent with established GNSS-based tracking architectures and hybrid GNSS–cellular localization approaches, particularly in terms of robustness and outdoor positioning reliability [6], [7]. Furthermore, the overall system performance is comparable to recently reported smart object and wearable tracking platforms, including backpack-oriented implementations, while emphasizing improved hardware integration and operational autonomy under practical conditions [9], [19].

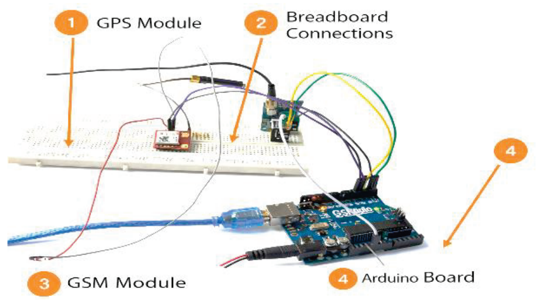
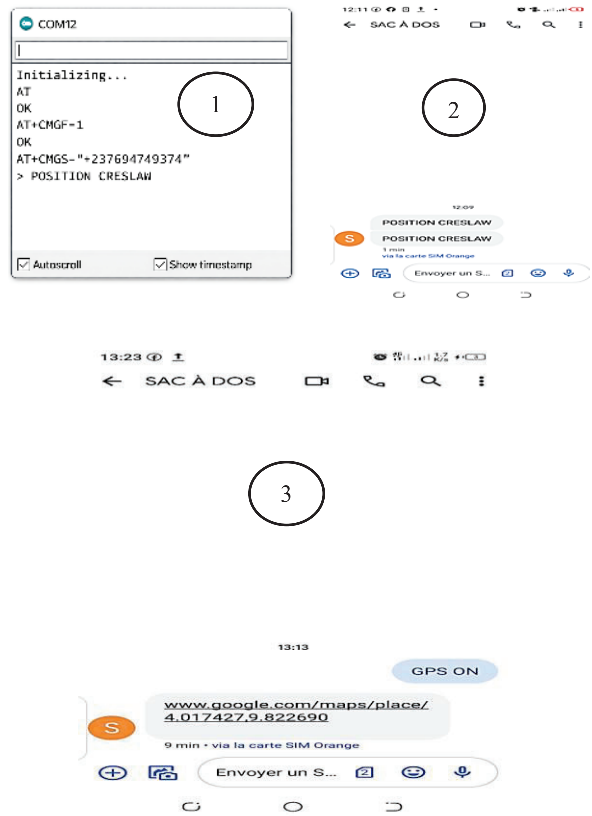


Fig. 7. Experimental test bench of the proposed geolocation system.

3.3 Results of the GPS Position Acquisition and SMS-Based Transmission Process

Fig. 8 illustrates the operational workflow of the proposed GPS–cellular localization system integrated into the smart backpack. Upon reception of a predefined SMS command, the cellular communication module forwards the request to the embedded controller, which dynamically activates the GPS module to acquire the current geographic coordinates. The extracted position is subsequently formatted and transmitted back to the user as a Google Maps link via SMS, enabling reliable remote localization without the need for continuous Internet connectivity. This event-driven localization strategy is consistent with low-power IoT tracking architectures and hybrid GNSS–cellular communication schemes designed to reduce energy consumption while maintaining robust long-range accessibility [3], [4], [8].
The adopted on-demand activation mechanism further enhances system autonomy and operational reliability, aligning with recent smart object and wearable tracking implementations that prioritize energy efficiency, modular integration, and user-triggered localization in real-world deployment scenarios [6], [19].



1- Reception of an SMS sent from the Arduino interface to the mobile phone
2- Screenshot of the message sent from the mobile phone to the Arduino system
3- Test of GPS-based geolocation coordinates acquisition

Fig. 8. Illustration of the GPS Position Acquisition and SMS-Based Transmission Process

3.4 Results of GPS-based geolocation coordinates acquisition

Fig. 9 illustrates the GPS-based geolocation coordinate acquisition performed by the proposed system during experimental validation. The obtained latitude and longitude values confirm the correct operation of the sensing, processing, and communication stages, enabling reliable outdoor position estimation. The visualization of the extracted coordinates on a cartographic interface further demonstrates the effective integration of signal acquisition, embedded computation, and data transmission modules within a unified architecture.
The reliability and consistency of the measured coordinates are influenced by satellite signal conditions and embedded system design constraints, which are key considerations in GNSS-based and hybrid localization platforms for portable objects [4], [6]. Moreover, the overall data interpretation process and system-level integration are consistent with established approaches in low-power measurement and localization systems, where hardware–software co-design plays a central role in ensuring robustness and accuracy [3], [11]. Similar integration strategies have been successfully

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adopted in smart object and wearable tracking platforms, confirming the practical applicability and robustness of the proposed localization system under real-world operating conditions [9], [19].

Fig. 9. Google Maps visualization of the GPS-based geolocation of the smart backpack

4- Conclusion

This paper presented the design and experimental validation of an embedded GPS–cellular geolocation system integrated into a smart backpack. The proposed architecture combines satellite-based positioning, cellular communication, and microcontroller-driven processing within a compact and energy-aware platform, enabling on-demand localization without continuous Internet connectivity.

Experimental evaluation demonstrated reliable coordinate acquisition, stable data transmission, and effective integration of sensing, processing, and communication modules under real operating conditions. These results confirm the practical feasibility of the proposed system for portable object tracking applications.

While the current implementation is based on a prototype, the proposed approach provides a solid foundation for future developments. Ongoing work will focus on system miniaturization, enhanced power management, and the integration of advanced localization and communication techniques to improve autonomy, scalability, and long-term deployment in smart personal object monitoring applications.

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