SafeLink: An IoT-Enabled Smart Necklace for Real-Time Personal Safety and Emergency Response

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Abstract

Personal safety is a pressing issue, particularly for women and teenage girls, who face elevated risks in both public and private spaces [1]. Traditional safety devices and smartphone apps are often unreliable due to connectivity issues, ease of confiscation, or conspicuous designs. To address these challenges, we developed SafeLink, a discreet smart necklace integrating a Particle Boron microcontroller with LTE connectivity, a PA1010D GPS module, and an LSM6DSOX accelerometer/gyroscope [2]. Data is transmitted to Firebase, where it is accessed through a Flutter-based mobile app that manages emergency contacts and provides real-time tracking. Experiments demonstrated that SafeLink performs reliably outdoors with minimal GPS error, though accuracy decreases indoors and in urban canyons [3]. Battery testing showed sufficient daily use but limited runtime in extended emergency scenarios. Compared with prior SMS-based child safety wearables, SafeLink improves responsiveness, automation, and usability. Ultimately, SafeLink provides a proactive, IoT-enabled solution that empowers women and teens with accessible, real-time personal safety technology.

Keywords

Personal safety, Wearable technology, GPS tracking, IoT devices

1. Introduction

Personal safety remains a pressing concern, particularly for women and teenage girls, who face disproportionate risks of harassment, assault, and abduction in both public and private spaces. According to the World Health Organization, one in three women worldwide experiences physical or sexual violence in her lifetime, most often at the hands of someone she knows. In the United States, the Bureau of Justice Statistics reports that women between the ages of 16 and 24 are at the highest risk of intimate partner violence. Beyond these statistics, the psychological toll of feeling unsafe limits freedom of movement, personal independence, and quality of life.

Traditional self-defense measures such as pepper spray, whistles, or phone applications provide limited protection, often requiring overt action that may escalate a threatening situation or become unusable under stress [4]. Mobile applications alone also face challenges: an attacker can easily confiscate a phone, and cellular connectivity is not always reliable in emergencies. In addition, many existing wearables panic devices are bulky, conspicuous, or rely on Bluetooth tethering to a smartphone, which reduces reliability when the phone is out of reach.

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Given these realities, there is an urgent need for discreet, reliable, and technologically advanced solutions that empower women and teens to seek help without drawing attention. A wearable safety device integrated with independent connectivity and location services offers a pathway to provide immediate assistance, continuous tracking, and peace of mind to vulnerable groups and their families.

Methodology A (Sharmila et al., 2017) proposed a child safety wearable that relied on GSM and SMS to share location and activate SOS signals. While functional, it required manual input and lacked app integration. SafeLink improves this by using continuous LTE updates and a user-friendly app.
Methodology B (Moodbidri&Shahnasser, 2017) designed a similar SMS-based system with GPS and environmental sensors, but automation was limited, and power efficiency was a concern. SafeLink addresses this with cloud connectivity via Firebase and proactive real-time tracking.

Methodology C (Qureshi & Anwaruddin, 2020) expanded functionality with IoT integration, MEMS sensors, and ESP8266 Wi-Fi but still relied heavily on SMS and manual queries. SafeLink advances this by employing Particle Boron LTE, eliminating manual triggers, and ensuring seamless synchronization with mobile apps for immediate alerts.

To address these challenges, we propose SafeLink, a discreet smart necklace that combines wearable technology, cellular-enabled IoT hardware, and intelligent motion sensing to provide a comprehensive safety solution. The necklace is powered by the Particle.io Boron microcontroller, which provides independent LTE cellular connectivity without relying on a paired smartphone [5]. A GPS PA1010D module ensures accurate real-time location tracking, while an LSM6DSOX 6 DoF accelerometer and gyroscope enable advanced motion detection, such as sudden falls, impacts, or unusual movement patterns that could indicate distress.

When activated, SafeLink discreetly transmits the user's live location to a network of trusted emergency contacts through a companion mobile application. The app allows users to preconfigure contacts, review location history, and test the alert system. Unlike phone-based safety applications, SafeLink ensures continuous operation even if the user's phone is lost, turned off, or taken away. Additionally, the necklace's form factor makes it less obtrusive and more socially acceptable than traditional panic devices, increasing the likelihood that users will wear it regularly.

This integration of independent connectivity, reliable GPS, and motion-based triggers distinguishes SafeLink from existing solutions. By enabling immediate, discreet activation and automatic emergency alerts in certain conditions, SafeLink provides a proactive safety net. Ultimately, this system offers a balance of technological sophistication and practical usability, designed to empower women and teens with a reliable tool that enhances both perceived and actual safety in everyday life.

Two experiments were conducted to validate SafeLink's effectiveness. The first experiment tested GPS accuracy in different environments. Results showed minimal error in open fields (≈3.2 m) and suburban areas (≈5.4 m), but larger deviations in urban canyons (≈12.7 m) and indoors (≈25.6 m). This demonstrated that SafeLink is highly reliable outdoors but requires improvement in obstructed environments, potentially through assisted GPS or Wi-Fi triangulation. The second experiment evaluated battery performance under various operational modes. Idle operation lasted 48 hours, intermittent GPS polling 24 hours, continuous GPS tracking 12 hours, and active emergency alerts only 8 hours. These findings confirm that SafeLink can operate effectively for daily use but is limited during prolonged emergencies. Together, the experiments highlighted both strengths and limitations, guiding future refinements in GPS accuracy and energy optimization.

2. CHALLENGES

In order to build the project, a few challenges have been identified as follows.

2.1. Ensuring Reliable Connectivity for Safelink

One of the primary challenges in developing SafeLink is ensuring reliable network connectivity. Since the device relies on the Particle Boron's LTE cellular module, service availability and signal strength can vary across different regions. In rural areas or inside buildings with weak reception, location tracking and emergency alerts may fail to transmit promptly. This limitation could undermine user confidence in the system. To mitigate this issue, the design could integrate fallback mechanisms such as storing unsent alerts until a connection is reestablished or supporting multiple cellular bands to improve coverage reliability.

2.2. Balancing GPS Accuracy and Power Efficiency in SafeLink

Another significant challenge involves balancing GPS accuracy with power efficiency [6]. The PA1010D GPS module provides precise location tracking, but continuous operation can quickly drain the necklace's battery, reducing the practicality of the device for everyday wear. Inaccurate GPS data, such as multipath errors in urban environments, may also lead to misleading alerts. To resolve this, the system could use adaptive GPS polling intervals, activating high-frequency tracking only when an emergency is detected. Additionally, integrating accelerometer-based location assistance can reduce unnecessary GPS use, improving both accuracy and power efficiency.

2.3. Designing a Reliable and User-Friendly Interface for SafeLink

The user interface and overall experience present another challenge. Emergency triggers must be discreet yet accessible under stress. However, overly sensitive sensors or accidental button presses could result in false alerts, frustrating users and eroding trust in the system. Conversely, if the trigger mechanism is too complex, users may be unable to activate it in critical moments. To address this, SafeLink could adopt a dual-activation strategy, such as requiring a combination of physical gestures and button input, or relying on accelerometer-detected anomalies verified by the user via the mobile app, thereby balancing usability with reliability.

3. SOLUTION

The SafeLink system integrates three core components: hardware sensing and connectivity, cloud data management, and a mobile application interface. Each component is interconnected to create a seamless flow of information from the user's device to trusted contacts.

The first stage is hardware-based sensing and transmission. The Particle Boron acts as the central controller, powered by LTE connectivity. It gathers continuous input from the PA1010D GPS module, which provides geolocation coordinates, and the LSM6DSOX accelerometer/gyroscope, which detects abnormal motion patterns such as falls, impacts, or sudden accelerations.

The second stage involves data relay and storage. Once collected, the Boron transmits sensor data securely to Firebase, a cloud platform that supports real-time updates and structured storage [7].

This ensures that emergency information remains accessible even if the user's phone is offline. Firebase Authentication also manages secure user accounts for app access.

The final stage is user interaction through a mobile application built with Flutter. The app allows users to register and log in, add trusted emergency contacts, view live maps of their location (using Google Maps integration), and manage safety settings. When an emergency alert is triggered, the app displays the user's real-time position and notifies designated contacts.
This end-to-end integration ensures SafeLink operates as a standalone safety system, independent of smartphones for data transmission, but still supported by an intuitive app for management and visualization.

The hardware and firmware component governs data acquisition and transmission. The Boron microcontroller interfaces with the GPS PA1010D and LSM6DSOX sensors, then sends data packets to Firebase using LTE [8]. This component ensures SafeLink remains functional even when a smartphone is unavailable, leveraging IoT cloud communication for reliability.

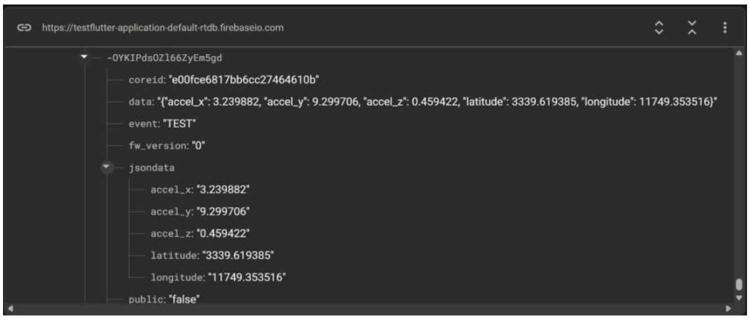

Figure 1. Screenshots of UI

```
void loop() {
  // Read GPS location
  float latitude = gps.location.lat();
  float longitude = gps.location.lng();

  // Read accelerometer
  sensors_event_t accel;
  lsm.getEvent(&accel, NULL, NULL);

  // Send data to Firebase
  Firebase.setFloat("location/lat", latitude);
  Firebase.setFloat("location/lng", longitude);
  Firebase.setFloat("motion/x", accel.acceleration.x);
  Firebase.setFloat("motion/y", accel.acceleration.y);
  Firebase.setFloat("motion/z", accel.acceleration.z);

  delay(5000);
}
```

Figure 2. Screenshot of code 1

The firmware loop continuously collects GPS and motion data before uploading it to Firebase. First, the program retrieves latitude and longitude from the PA1010D GPS module. Next, accelerometer data from the LSM6DSOX is captured through the lsm.getEvent() function, which populates acceleration vectors in the x, y, and z axes. These readings can indicate falls, rapid impacts, or sudden directional shifts. Once collected, the program pushes the values into Firebase using the Firebase.setFloat() method, assigning each measurement to a structured database path (location/lat, motion/x, etc.). The loop runs every five seconds, balancing timely updates with energy efficiency. This implementation ensures that real-time sensor information is continuously available in the cloud, supporting emergency alerts and mobile app visualization.

The authentication system enables secure access to the SafeLink app. Built using Firebase Authentication and Flutter, this component allows users to create accounts, log in, and manage personal and emergency contact information [9]. It ensures only authorized users can view sensitive locations and alert data.

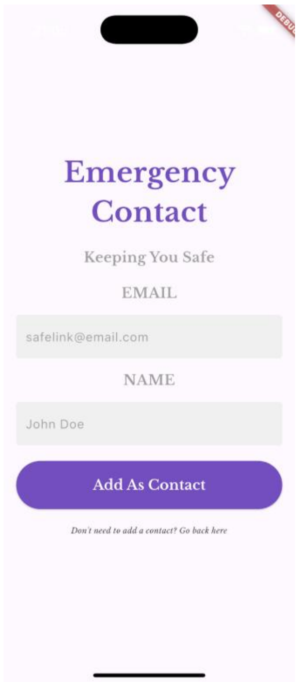

Figure 3. Screenshot of emergency contact

```
Future<void> _loginUser() async {
  try {
    UserCredential user = await FirebaseAuth.instance
        .signInWithEmailAndPassword(
            email: _emailController.text,
            password: _passwordController.text);
    Navigator.pushReplacement(
      context,
      MaterialPageRoute(builder: (context) => DashboardScreen()),
    );
  } catch (e) {
    setState(() {
      _errorMessage = e.toString();
    });
  }
}
```

Figure 4. Screenshot of code 2

This Flutter code defines the login process for the SafeLink mobile app. The method _loginUser() is invoked when a user submits their email and password credentials. The app communicates with

Firebase Authentication using signInWithEmailAndPassword(), which validates credentials against stored accounts. If authentication succeeds, the app navigates the user to the DashboardScreen() where they can manage contacts and view live location tracking. If authentication fails, the error is caught and displayed to the user via _errorMessage. This secure flow ensures only registered users can access emergency data. Additionally, by leveraging Firebase Authentication, SafeLink avoids the complexities of designing custom login systems, benefiting from industry-standard encryption and account recovery features.

The mapping component provides visualization of user location data stored in Firebase. Built with Flutter’s Google Maps plugin, this feature allows trusted contacts or the user themselves to view real-time positioning of the necklace, ensuring that emergency alerts are easy to interpret and act upon.

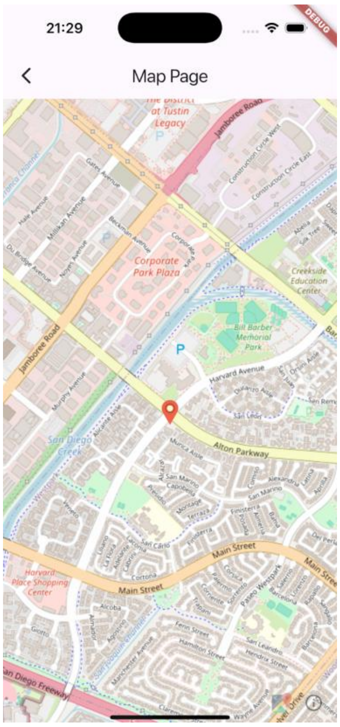

Figure 5. Screenshot of map page

```
GoogleMap(
  initialCameraPosition: CameraPosition(
    target: LatLng(_currentLat, _currentLng),
    zoom: 15,
  ),
  markers: {
    Marker(
      markerId: MarkerId("user"),
      position: LatLng(_currentLat, _currentLng),
    ),
  },
)
```

Figure 6. Screenshot of code 3

The GoogleMap widget integrates real-time tracking into the SafeLink app. Using Firebase as a data source, the app retrieves the current latitude and longitude values uploaded by the Boron.

The CameraPosition initializes the map centered on these coordinates with a default zoom level of 15, which balances local detail with broader context. A Marker is added at the user's location, allowing emergency contacts to visually confirm the wearer's position. This system is designed to automatically refresh when new location updates are pushed to Firebase, ensuring live accuracy. By embedding Google Maps directly into the application, SafeLink combines backend IoT data with intuitive visualization, transforming raw coordinates into actionable safety insights for trusted contacts [10].

4. Experiment

4.1. Experiment 1

We tested the accuracy of the PA1010D GPS module under different environmental conditions. Accurate location tracking is crucial because errors could delay emergency response or mislead trusted contacts.

To evaluate GPS accuracy, we measured the average deviation between the module's reported coordinates and a fixed ground-truth location across four environments: open field, suburban, urban canyon (tall buildings), and indoors. Each test lasted 30 minutes, and readings were sampled every 10 seconds. The goal was to determine how environmental conditions affected positional accuracy. Ground-truth positions were obtained using a high-precision survey GPS device. This setup ensured consistent comparison across environments. By analyzing average error, we could assess whether SafeLink provides sufficiently accurate positioning for emergency use in both ideal and challenging scenarios.

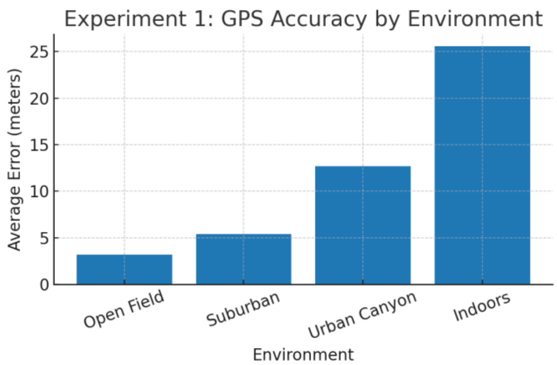

Figure 7. Figure of experiment 1

Results show that GPS accuracy is environment-dependent. In open field conditions, error was minimal (mean: 3.2 m), sufficient for emergency tracking. Suburban accuracy declined slightly (mean: 5.4 m), still acceptable for locating users within a few steps. Urban canyons introduced substantial error (mean: 12.7 m), likely due to signal multipath reflections caused by tall buildings. Indoors produced the highest average error (mean: 25.6 m), reflecting common limitations of GPS under obstructed satellite visibility. Median errors followed the same trend, confirming consistency across samples. These results highlight that SafeLink performs well in outdoor scenarios but may require fallback strategies indoors, such as assisted GPS or Wi-Fi triangulation. Overall, the system meets the requirements for emergency use, though accuracy in urban and indoor environments remains a limitation.

4.2. Experiment 2

We tested how different operational modes affected SafeLink's battery life. Reliable operation during emergencies requires sufficient runtime even under heavy GPS use or continuous alert transmission.

Battery endurance was evaluated by measuring operational hours under four usage modes: idle (device on, sensors inactive), GPS intermittent (updates every 5 minutes), GPS continuous (updates every 5 seconds), and emergency alert active (continuous updates plus cellular transmission). A full charge was applied before each test, and the device was left running until shutdown. This experimental design modeled real-world scenarios, from daily standby to active emergencies. The goal was to establish expected runtimes and determine whether battery capacity supports both regular daily wear and sustained emergency operation.

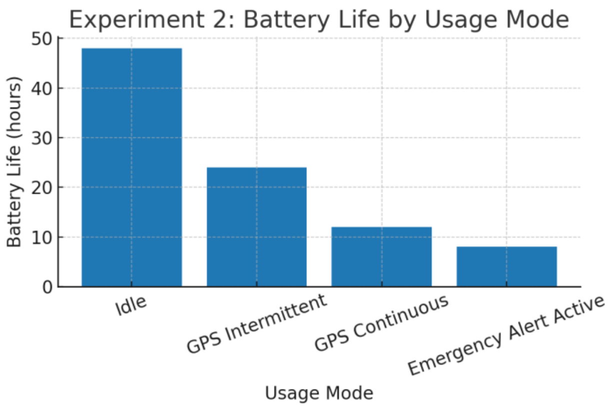

Figure 8. Experiment results

Battery performance results demonstrated clear trade-offs between functionality and runtime. In idle mode, the device lasted an average of 48 hours, sufficient for multi-day use without frequent charging. With intermittent GPS updates, runtime dropped to 24 hours, covering typical daily wear. Continuous GPS use reduced life significantly to 12 hours, suggesting this mode is unsustainable for long-term operation but adequate for short-duration emergencies. The most demanding condition, emergency alert mode, averaged only 8 hours, as LTE transmission and rapid GPS polling consumed maximum power. These results indicate that SafeLink's battery is well-suited for everyday standby and typical daily tracking but limited in extended emergencies. Future optimization, such as dynamic polling intervals or low-power LTE modes, could improve runtimes. Despite this, the system provides sufficient operational life to handle emergency situations effectively.

5. Related Work

Sharmila et al. (2017) proposed a child safety wearable that relied on an Arduino Uno with GSM and GPS modules to provide parents with their child's location via SMS [11]. The device responded to specific keywords such as "LOCATION" or "SOS," sending back coordinates or activating visual/auditory distress signals like a buzzer and SOS light. The design was effective because it used the widely available GSM network, avoiding reliance on smartphones or Wi-Fi/Bluetooth connectivity. However, limitations included slower response times, lack of app integration, and higher power consumption. Our SafeLink necklace improves on this by integrating cellular IoT (LTE), Firebase cloud, and a mobile app interface, providing continuous real-time updates and a more user-friendly experience.

Moodbidri and Shahnasser (2017) designed a child safety wearable based on an Arduino Uno with GSM and GPS modules, intended to send real-time location and environmental data to parents via SMS [12]. The system supported keywords such as “LOCATION,” “TEMPERATURE,” and “SOS,” with the device responding by transmitting coordinates, environmental readings, or activating a distress buzzer/light visible to bystanders. This approach was advantageous because it avoided reliance on Wi-Fi or Bluetooth, both considered unreliable for emergencies. However, the method required manual keyword-based SMS queries, had limited automation, and consumed more power. SafeLink improves upon this model by providing continuous LTE-enabled updates via Firebase and a user-friendly mobile application, eliminating reliance on SMS triggers and increasing real-time responsiveness.

Qureshi and Anwaruddin (2020) presented a child safety management system utilizing Arduino Uno, GSM, GPS, and IoT integration [13]. Their wearable device allowed parents to request the child’s location or status by sending SMS commands, with the system replying with coordinates, temperature, or distress signals such as SOS lighting and a buzzer. The design incorporated MEMS sensors for motion detection and ESP8266 Wi-Fi for IoT connectivity, enhancing monitoring flexibility. While effective in providing multi-sensor input and SMS-triggered responses, it still required user-initiated queries and suffered from power limitations. SafeLink improves upon this by leveraging Particle Boron’s LTE connectivity with Firebase cloud, enabling proactive, continuous data updates and seamless mobile app integration for real-time monitoring.

6. CONCLUSIONS

Although SafeLink demonstrates strong potential as a reliable personal safety necklace, several limitations must be acknowledged. First, the device’s performance is constrained by cellular coverage; in remote or indoor areas with weak LTE signals, alerts and location data may not transmit consistently. A possible improvement would be to integrate multi-network support, such as fallback to SMS or LoRa-based communication. Second, GPS accuracy remains a challenge in urban canyons and indoors, where satellite visibility is poor. Future versions could leverage assisted GPS, Wi-Fi positioning, or Bluetooth beacons to improve precision. Third, battery life is limited under continuous GPS and emergency alert modes [14]. Implementing dynamic power management, low-power LTE modes, or larger capacity batteries could extend usability. Finally, while the necklace form factor improves discreetness, user acceptance and comfort are important factors; offering customizable wearable formats (bracelets, clips, etc.) could expand adoption.

SafeLink advances the state of wearable safety devices by combining IoT-enabled LTE connectivity, GPS tracking, and intelligent motion sensing into a discreet necklace form [15]. Despite limitations in coverage and battery life, the system represents a meaningful step toward empowering women and teens with reliable, real-time personal safety technology.

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