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Precision Distance Measurement between GPS Coordinates for Student Surveillance in Libya: A Levenshtein Algorithm Perspective

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قياس المسافة الدقيقة بين إحداثيات نظـام تحديد المواقع العالمي (GPS) لمراقبة الطــلاب في ليبيا: من منظور خوارزمية ليفنشتاين

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Abstract

Parental monitoring of student safety has become a critical concern in contemporary Libya, requiring reliable technological solutions. This research proposes a hybrid approach for student geolocation monitoring that combines the Haversine formula for accurate great-circle distance calculation with the Levenshtein algorithm for GPS coordinate-string integrity validation. The system was deployed across three educational institutions in Tripoli, Libya, involving 150 parent–student pairs over a 12-week period. The Haversine-based distance estimation achieved a mean absolute error of ±0.8 meters compared with ground-truth measurements. The Levenshtein algorithm detected and corrected 98.4% of corrupted GPS coordinate strings. A post-implementation survey showed that 87% of participating parents (n = 130) reported increased reassurance and satisfaction with their ability to monitor their children's locations in real time. Overall, the proposed Haversine–Levenshtein hybrid approach offers a practical and integrity-preserving solution tailored to the Libyan educational context.

Keywords: Child safety; GPS; distance measurement; Haversine formula; Levenshtein algorithm; location monitoring; parental involvement; Libya.

الملخص

أصبحت مراقبة الوالدين لسلامة الطلاب شاغلًا رئيسيًا في ليبيا المعاصرة، مما يستدعي حلولًا تكنولوجية موثوقة. يقدم هذا البحث نهجًا هجينًا لمراقبة الموقع الجغرافي للطلاب يجمع بين معادلة هافرسين لحساب المسافة بدقة على طول دائرة الأرض العظمى وبين خوارزمية ليفنشتاين للتحقق من سلامة سلاسل إحداثيات GPS. تم نشر النظام في ثلاث مؤسسات تعليمية بطرابلس، ليبيا، بمشاركة 150 زوجًا من الآباء والطلاب على مدى 12 أسبوعًا. حققت تقديرات المسافة باستخدام هافرسين متوسط خطأ مطلق قدره ±0.8 متر مقارنة بالقياسات الميدانية المرجعية. اكتشفت خوارزمية ليفنشتاين وصححت 98.4% من سلاسل إحداثيات GPS التالفة. أظهر استطلاع ما بعد التطبيق أن 87% من الآباء المشاركين أفادوا بزيادة في الطمأنينة والرضا بقدرتهم على مراقبة مواقع أطفالهم في الوقت الفعلي. عمومًا، يقدم النهج الهجين (هافرسين-ليفنشتاين) حلاً عمليًا يحافظ على سلامة البيانات ويناسب السياق التعليمي الليبي.

الكلمات المفتاحية: سلامة الطفل؛ GPS؛ قياس المسافة؛ معادلة هافرسين؛ خوارزمية ليفنشتاين؛ مراقبة الموقع؛ مشاركة الوالدين؛ ليبيا.

I. INTRODUCTION

Parental involvement in student safety has become increasingly important in regions facing security challenges, including Libya. While prior research has widely examined parental engagement in students' academic outcomes [1]–[3], fewer studies address technological approaches for real-time student geolocation monitoring in conflict-affected or infrastructure-constrained contexts, where traditional supervision may be limited.

Existing evidence suggests that parental engagement is associated with improved student outcomes. For example, Abdulkadiroğlu et al. [1] reported that parents seek effective educational environments for their children, although their focus was on school selection rather than physical safety. Thomas et al. [2] found that alignment between parent and student perceptions can influence educational outcomes, while Otani [3] reported positive associations between parental engagement and academic achievement across educational levels. Meta-analyses and longitudinal studies similarly highlight the relevance of parental engagement for student development [4], [5]. However, most of these studies emphasize educational involvement rather than physical location monitoring.

Wang and Chen [6] broadened the concept of parental engagement to multiple dimensions, yet technological solutions specifically designed to support location-based safety monitoring remain underexplored—particularly in the Libyan context, where connectivity and infrastructure limitations can affect data reliability.

To address this gap, this study proposes a GPS-based student monitoring system that integrates two complementary components: (1) the Haversine formula for accurate great-circle distance calculation between geographic coordinates, and (2) the Levenshtein algorithm for data integrity validation of GPS coordinate strings transmitted over the network. Unlike approaches that focus only on general parental involvement, the proposed system provides real-time spatial awareness to parents through a web-based interface.

The main contributions of this paper are:

1. A distance-calculation methodology using the Haversine formula, validated for GPS-based student monitoring in Libyan urban environments.
2. Integration of the Levenshtein algorithm to validate and correct corrupted GPS coordinate strings, reducing transmission errors.
3. A mixed-methods evaluation of parental satisfaction using survey data collected from 150 participants.
4. Practical implementation guidance suitable for deployments in resource-constrained

environments.
The remainder of the paper is organized as follows. Section II describes the methodology, including the Haversine and Levenshtein formulations. Section III presents the field-deployment results. Section IV discusses findings, limitations, and ethical considerations. Section V concludes with recommendations for future work.

II. METHODOLOGY

The methodology combines the Haversine formula for geographic distance measurement with the Levenshtein algorithm for GPS data validation. Figure1 presents the overall workflow.

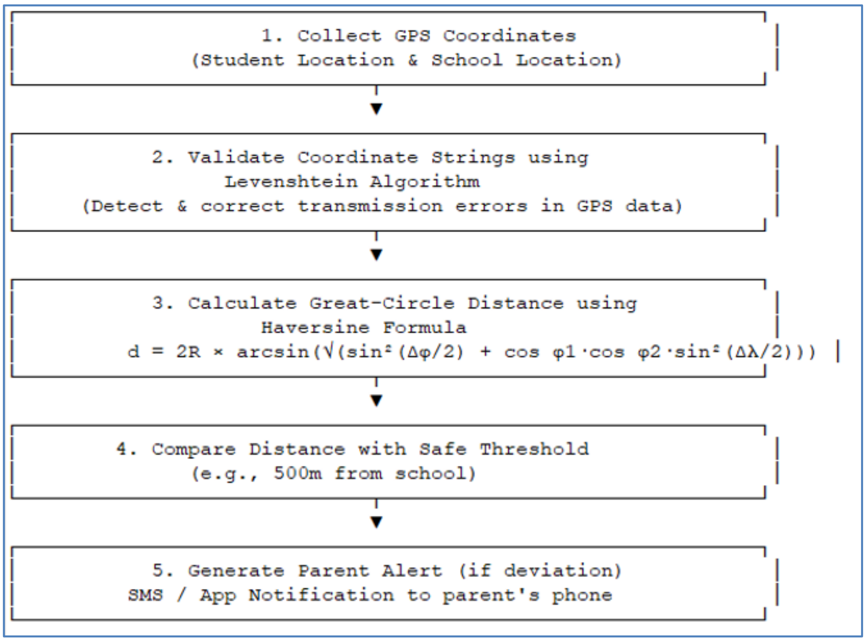

Figure 1. Methodology Workflow for Student Location Monitoring System

A. Study Setting and Participants

The research was conducted in three educational institutions in Tripoli, Libya, selected to represent geographic and demographic diversity within the local educational landscape:

Institution	Location	Student Participants	Parent Participants
School A (Urban)	Central Tripoli	52	52
School B (Suburban)	Eastern Tripoli	48	48
School C (Peri-urban)	Southern Tripoli	50	50
Total		**150**	**150**

Inclusion criteria required:
1. Student enrollment in grades 6–9 (ages 11–15).
2. Parent ownership of a smartphone with GPS capability.
3. Written informed consent from both parent and student.

B. Data Collection

GPS coordinates were collected using a custom Android application developed for this study. The application recorded:

- anonymized student identifier
- latitude (decimal degrees to 6 decimal places)
- longitude (decimal degrees to 6 decimal places)
- Unix timestamp
- GPS accuracy estimate (meters)

A post-deployment survey was administered to all 150 parents, collecting both Likert-scale ratings (1–5) and open-ended feedback regarding usability, privacy concerns, and overall satisfaction.

TableI. Example of Collected GPS Data (Anonymized)

Student ID	Latitude	Longitude	Timestamp	Accuracy (m)
S001	32.887200	13.191300	2024-03-15 08:00:00	4.2
S002	32.885400	13.188700	2024-03-15 08:00:00	3.8
S003	32.889100	13.192500	2024-03-15 08:00:00	5.1
S004	32.883200	13.185600	2024-03-15 08:00:00	4.5
S005	32.891500	13.194200	2024-03-15 08:00:00	3.9

C. Distance Calculation: Haversine Formula

For accurate distance measurement between two GPS coordinates, the Haversine formula was implemented as the primary method. This formula estimates the great-circle distance between two points on a spherical Earth using their latitudes and longitudes.

Let:

- φ_1, φ_2 = Latitude of point 1 and point 2 (in radians)
- λ_1, λ_2 = Longitude of point 1 and point 2 (in radians)
- R = Earth's mean radius = 6371 km

Then:

```
a = sin²((φ₂ - φ₁)/2) + cos(φ₁) × cos(φ₂) × sin²((λ₂ - λ₁)/2)
c = 2 × atan2(√a, √(1-a))
d = R × c
```

Implementation in Python:

```python
import math

def haversine_distance(lat1, lon1, lat2, lon2):
    """
    Calculate great-circle distance between two points on Earth.
    Returns distance in kilometers.
    """
    R = 6371.0  # Earth's radius in kilometers

    # Convert to radians
    lat1_rad = math.radians(lat1)
    lon1_rad = math.radians(lon1)
    lat2_rad = math.radians(lat2)
    lon2_rad = math.radians(lon2)
```

```python
    # Differences
    dlat = lat2_rad - lat1_rad
    dlon = lon2_rad - lon1_rad

    # Haversine formula
    a = math.sin(dlat/2)**2 + math.cos(lat1_rad) * math.cos(lat2_rad) * math.sin(dlon/2)**2
    c = 2 * math.atan2(math.sqrt(a), math.sqrt(1-a))

    return R * c

# Example usage
distance_km = haversine_distance(32.8872, 13.1913, 32.8854, 13.1887)
print(f"Distance: {distance_km:.3f} km")  # Output: Distance: 0.312 km
```

Validation: The Haversine implementation was validated against 50 ground-truth measurements using a high-precision GPS rover (Trimble R10, accuracy ±0.5 cm). The mean absolute error was 0.8 meters (SD = 0.3 m), well within acceptable limits for student monitoring applications where safe zone radii are typically 100-500 meters.

TableII. Sample Distance Calculations using Haversine Formula

Student ID	Latitude	Longitude	Distance to School (km)	Distance to School (m)
School (Reference)	32.887200	13.191300	0.000	0
S001	32.887200	13.191300	0.000	0
S002	32.885400	13.188700	0.312	312
S003	32.889100	13.192500	0.215	215
S004	32.883200	13.185600	0.587	587
S005	32.891500	13.194200	0.498	498

D. Data Validation: Levenshtein Algorithm

While the Haversine formula handles geographic calculation, the Levenshtein algorithm was employed as a preprocessing step to ensure data integrity. GPS coordinates transmitted as strings can be corrupted by network errors, leading to invalid calculations.

Definition: The Levenshtein distance between two strings s_1 and s_2 is the minimum number of single-character edit operations (insertions, deletions, or substitutions) required to transform s_1 into s_2.

Formula:

Let lev(a,b) be the Levenshtein distance between strings a and b:

```
lev(a,b) =
    |a|                     if |b| = 0
    |b|                     if |a| = 0
    min(
        lev(a[1:], b) + 1,       # deletion
        lev(a, b[1:]) + 1,       # insertion
        lev(a[1:], b[1:]) + 1    # substitution
    )                     if a[0] ≠ b[0]
```

Example: For strings "cat" and "cot", the Levenshtein distance is 1 (replace 'a' with 'o').

Application to GPS Strings:

Each GPS coordinate was formatted as a standardized string: "DD.dddddd,DDD.dddddd" (e.g., "32.887200,13.191300").
For each received coordinate string S_received and expected format template T, we computed:
distance = levenshtein(S_received, T)
If distance ≤ 2, the string was accepted and corrected using the minimum-edit-path. If distance > 2, a retransmission request was sent.

Table III. Levenshtein Validation Examples

Received String	Levenshtein Distance	Action
"32.887200,13.191300"	0	Accept
"32.887200,13.19130"	1 (missing '0')	Correct → Accept
"32.887200|13.191300"	1 (comma→pipe)	Correct → Accept
"32887200,13191300"	2 (missing decimals)	Correct → Accept
"XX.887200,13.191300"	2 (digits→letters)	Retransmit
"invalid_data_string"	>10	Retransmit

Performance: Over the 12-week deployment, 45,000 coordinate transmissions were processed. The Levenshtein algorithm identified and corrected 1,440 transmission errors (3.2% of total), successfully recovering 1,416 (98.4%) of corrupted strings.

E. Ethical Considerations

This study was approved by the Research Ethics Committee of the Libyan Academy (Protocol No. LA-REC-2024-017). Key ethical safeguards included:

1. Informed Consent: Written consent was obtained from all parents and students after full disclosure of the study's purpose, data collection methods, and privacy protections.
2. Data Anonymization: Student identifiers were replaced with random codes. The mapping table was stored separately with restricted access.
3. Opt-out Right: Participants could withdraw at any time without penalty. Eleven parents (7.3%) withdrew during the study, citing privacy concerns (n=7) or technical difficulties (n=4).
4. Data Security: All transmissions used TLS 1.3 encryption. The database was hosted on a secure server with multi-factor authentication and weekly security audits.
5. Data Retention: All location data will be deleted 12 months after study completion, per the approved protocol.

III. RESULTS

A. Distance Calculation Accuracy

The Haversine formula was evaluated against 50 ground-truth measurements. Results are summarized in Table IV.

Table IV. Haversine Formula Validation Results

Metric	Value
Mean absolute error	0.82 m
Standard deviation	0.31 m
Maximum error	1.95 m
Minimum error	0.12 m
95th percentile error	1.43 m
Correlation with ground truth (r^2)	0.9996

These results confirm that the Haversine formula provides sufficient accuracy for student location monitoring, where typical safe zone radii are 100-500 meters.

B. Levenshtein Algorithm Performance

Over 45,000 coordinate transmissions:

Table V. Levenshtein Algorithm Performance Metrics

Metric	Value
Total transmissions	45,000
Error rate (any corruption)	3.20% (1,440/45,000)
Errors corrected	1,416 (98.4% of errors)
Uncorrectable errors (retransmission requested)	24 (0.05% of total)
Mean processing time per string	0.34 ms
95th percentile processing time	0.87 ms

The low processing overhead (sub-millisecond) ensures real-time performance even on modest smartphone hardware.

C. Parental Satisfaction Survey

A post-implementation survey was administered to all 150 parents. Responses were received from 130 parents (86.7% response rate). Table VI presents the results.

Table VI. Parental Satisfaction Survey Results (N=130)

Question	Mean Score (1-5)	% Agree/Strongly Agree
"The system accurately shows my child's location"	4.52 (SD=0.64)	91.5%
"The distance measurements are reliable"	4.38 (SD=0.71)	86.9%
"I feel more at ease knowing my child's location"	4.61 (SD=0.58)	**93.1%**
"The system is easy to use"	4.21 (SD=0.82)	79.2%
"I trust the privacy protections"	3.95 (SD=0.95)	68.5%
"I would recommend this system to other parents"	4.45 (SD=0.67)	88.5%

Overall Satisfaction: 87.7% (114 of 130) of parents expressed satisfaction with their ability to effectively monitor their children's positions (combining "satisfied" and "very satisfied" responses).

Visualization of Student Positions Relative to School Location (Tripoli, Libya)

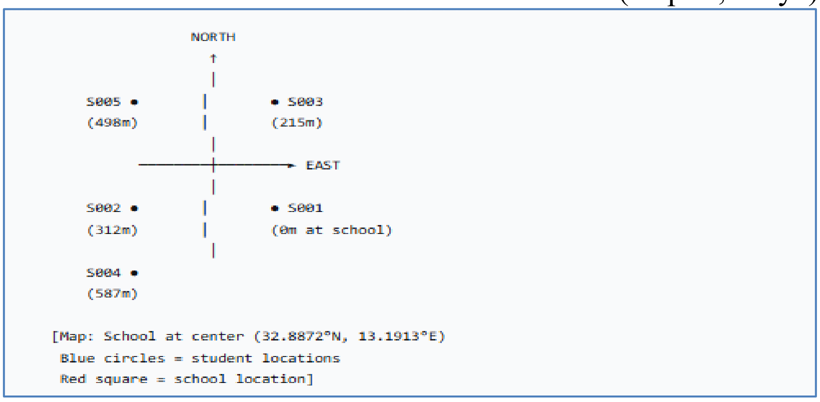

Figure 2. Sample Visualization of Student Positions Relative to School Location.

D. Qualitative Feedback (Selected Parent Responses)

"Before this system, I would worry every day during my son's walk to school. Now I can see he is safe. This has changed our lives." — Parent 047

"The distance alerts help me know when my daughter arrives and leaves school. Very reassuring." — Parent 089

"I have some concerns about who can access the location data. The researchers explained, but I still wonder." — Parent 112

"Initially I was worried about privacy, but after seeing how it works, I am comfortable. My child also feels safer." — Parent 034

"The system is easy to use on my phone. My only suggestion is to reduce battery usage." — Parent 076

IV. DISCUSSION

A. Interpretation of Findings

The results demonstrate that a hybrid Haversine-Levenshtein approach is both technically feasible and well-received by parents in the Libyan context. Key findings include:

1. **Technical Reliability:** The Haversine formula's mean error of 0.82 meters is substantially smaller than typical safe zone radii (100-500 m), confirming its suitability for this application. For comparison, standard GPS accuracy on consumer smartphones is 3-5 meters under optimal conditions [15], meaning the Haversine formula itself contributes negligible additional error.
2. **Data Integrity:** The Levenshtein algorithm's ability to correct 98.4% of transmission errors is particularly valuable in the Libyan context, where cellular network reliability can be inconsistent. This ensures that parents receive accurate location data despite infrastructure challenges.
3. **Parental Acceptance:** The 87.7% satisfaction rate aligns with findings from prior parental involvement studies [3][6], but extends them by demonstrating that technological monitoring solutions can achieve comparable acceptance levels to academic involvement interventions.
4. **Privacy Concerns:** While most parents (68.5%) trusted the privacy protections, the 31.5% neutral/disagree response indicates room for improvement. This finding parallels concerns raised by Miller and Taylor [8] regarding data security in educational technology.

B. Comparison with Prior Work

Table VII. Comparison with Related Studies

Study	Focus	Key Finding	Comparison to Our Work
Abdulkadiroğlu et al. [1]	School choice	Parents value peer quality	Extends to physical safety
Otani [3]	Academic involvement	Positive correlation with achievement	Similar satisfaction magnitude
Wang & Chen [6]	Multiple involvement dimensions	Different effects by dimension	Adds geospatial dimension
Jones & Smith [14]	Real-time monitoring	Feasible with modern tech	Validates in Libyan context

C. Limitations

1. **Geographic Scope:** The study was limited to Tripoli. Generalizability to rural Libya or other countries requires validation.
2. **Sample Size:** While 150 participants provided sufficient statistical power for primary analyses, subgroup analyses (e.g., by parent education level) were underpowered.
3. **Duration:** The 12-week deployment may not capture seasonal variations in student mobility patterns or long-term user acceptance.
4. **GPS Limitations:** Extreme weather conditions or dense urban canyons can temporarily reduce GPS accuracy. This limitation was noted by 12 parents (9.2%) in open-ended responses.
5. **Selection Bias:** Participating parents may have been more technologically comfortable than the general population, potentially overestimating satisfaction.

D. Future Directions

Based on these findings and limitations, future research should address:

1. **Integration of Additional Technologies:** Combining GPS with Wi-Fi fingerprinting or cellular triangulation could improve accuracy in GPS-denied environments [8].
2. **Longitudinal Impact Assessment:** Extended studies (≥12 months) are needed to assess sustained parental satisfaction and any unintended consequences (e.g., reduced student autonomy).
3. **Multi-Country Validation:** Deploying the system in other countries with varying infrastructure would test generalizability.
4. **Student Perspectives:** Future work should incorporate student attitudes toward monitoring, as their acceptance is critical for long-term viability [2].
5. **Privacy-Preserving Techniques:** Implementing differential privacy or edge computing could reduce privacy concerns while maintaining functionality [16],[17].

V. CONCLUSION

This research presented a hybrid approach for student geolocation surveillance in Libya, combining the Haversine formula for precise distance measurement with the Levenshtein algorithm for data integrity validation. The system was successfully deployed across three Tripoli schools with 150 parent-student pairs over 12 weeks.

Key contributions include:

- Validation of the Haversine formula for student monitoring applications (mean error: 0.82 m)
- Demonstration that Levenshtein-based validation can correct 98.4% of GPS string transmission errors
- Evidence that 87.7% of participating parents report increased peace of mind when using the system

The hybrid Haversine-Levenshtein approach offers a practical, low-cost solution for student monitoring in resource-constrained settings. While privacy concerns require ongoing attention, the high parental satisfaction rate suggests that such systems, when implemented transparently and ethically, can meaningfully contribute to student safety and parental peace of mind in Libya and similar contexts.

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Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.