Bridging the Desktop-Mobile Divide: Regional Optimization of Ghana's National Grid for Mobile and Web Applications

Isaac Tetteh-Apotey

Geomatics Engineer, Ghana Institution of Surveyors (GhIS)

MSc Software Engineering Candidate

Quantic School of Business and Technology

Accra, Ghana

tettehapotey@gmail.com

ORCID: 0009-0008-6360-5847

Abstract—This paper presents an empirical optimization of Ghana National Grid coordinate transformation parameters validated across 259 control points from a comprehensive 490-point database, revealing critical coastal/inland accuracy variations and desktop-mobile implementation inconsistencies. The research demonstrates that published parameters achieve exceptional 1.3-meter accuracy in Western (coastal) Region but degrade to 61.7 meters in Upper East (far north), while the optimized parameters provide 26% average improvement for inland Ghana (28.4 m to 21.1 m RMS). Greater Accra shows the greatest benefit with 70% error reduction (6.9 m to 2.1 m RMS) using parameters specifically optimized for that region. The study uncovers a critical implementation discrepancy. Desktop GIS software (Topcon, ArcGIS, QGIS) uses a false easting of 900,000 meters. Meanwhile, mobile/web applications typically use 274,291.3 meters, which is approximately 900,000 feet. The system enables immediate verification of cadastral plan coordinate consistency. This transforms a traditionally multi-hour, error-prone office process into a 30-second field operation. This work provides both an immediately useful professional tool and a reproducible framework for adapting national grids to mobile-first digital workflows while addressing critical interoperability challenges in Ghana's geospatial ecosystem.

Index Terms—Ghana National Grid, Coordinate Transformation, Regional Parameter Optimization, Coastal/Inland Divide, Mobile GIS, Desktop-Mobile Interoperability, Cadastral Systems, Flutter, React Native

I. Introduction

Coordinate transformation is a core operation in surveying and geomatics engineering, forming the bridge between field measurements, cadastral documentation, and spatial visualization. In Ghana, cadastral plans are traditionally prepared using the Ghana National Grid, with coordinates expressed in **feet**, while modern navigation, reconnaissance, and public-facing visualization depend on geographic coordinates referenced to global datums and displayed on satellite imagery.

In practice, this disconnect introduces significant friction. Surveyors, valuers, and even financial institutions often cannot immediately locate a parcel of land from a cadastral plan without post-processing the coordinates using desktop software, exporting Keyhole Markup Language (KML) files, and loading them into web mapping platforms. Less technically inclined practitioners may be unable to perform this workflow at all without physically visiting the site or relying on local knowledge and landmarks.

Gap 1: Unit Mismatch in Input Formats

A primary limitation of existing geospatial tools is their unit handling. Most coordinate transformation applications—whether desktop or web-based—require input in **meters**, despite the fact that Ghanaian cadastral plans are exclusively prepared in **feet**. This forces surveyors to manually convert all coordinates from feet to meters before using these tools, introducing unnecessary steps, calculation errors, and workflow delays.

Gap 2: Input Format Mismatch

Compounding this issue is the format mismatch for geographic coordinates. Most conversion applications support only decimal degree (DD) input, despite cadastral plans in Ghana being commonly annotated in degrees-minutes-seconds (DMS). Users must therefore perform **double conversion**: first from feet to meters for grid coordinates, then from DMS to DD for geographic coordinates—both error-prone manual processes.

Gap 3: Regional Parameter Optimization

A fundamental limitation of current Ghana Grid implementations is the assumption of uniform nationwide accuracy. Practitioners have observed consistent positional offsets when using published transformation parameters, yet there is limited guidance on systematic optimization. This research reveals a coastal/inland divide in Ghana that requires region-specific parameter sets. Published parameters work optimally in the Western Region but perform poorly inland. Conversely, optimized parameters significantly improve inland accuracy but degrade coastal performance.

Gap 4: Control Points Accessibility

Beyond coordinate transformation, field surveyors face significant challenges accessing Ghana's geodetic control network. Official control point data (EX-Data) is distributed in static, non-spatial formats (printed sheets) without location metadata for navigation. This forces practitioners to rely on informal

knowledge networks, verbal directions, or professional messaging groups to locate control points, creating inefficiencies and potential errors in field operations.

Gap 5: Desktop-Mobile Implementation Inconsistency
A critical discovery from this research is that desktop GIS software (Topcon, ArcGIS, QGIS) and GPS receivers use a false easting of 900,000 meters for Ghana Grid, while mobile/web applications typically use 274,291.3 meters (approximately 900,000 feet). This inconsistency creates interoperability problems when surveyors attempt to use coordinates across different platforms, potentially causing significant errors in field operations.

Gap 6: Cadastral Plan Coordinate Verification
Cadastral plans in Ghana often contain coordinate discrepancies that are difficult to detect without specialized software. Grid coordinates (in feet) and geographic coordinates (in DMS) printed on the same plan may not align due to manual conversion errors during drafting. Currently, verification requires multiple software tools, manual unit conversions, and hours of processing time—making routine quality checking impractical, especially in field conditions.

This research addresses all six gaps by developing an integrated, production-grade mobile geospatial suite that:

1) Provides **region-aware coordinate conversion** with empirically optimized parameters for inland Ghana and published parameters for coastal regions.
2) Accepts grid coordinates **directly in feet** and geographic coordinates in **DMS or DD formats**, matching local documentation practices.
3) Implements **one-click batch CSV processing** to solve workflow bottlenecks for researchers, students, and professionals handling large coordinate sets.
4) Provides a **searchable database of 490 control points** with map integration for field navigation, addressing data accessibility gaps.
5) Includes an **embedded interactive tutorial** with verified test data, enabling immediate user verification and reducing adoption barriers.
6) Employs a **dual-app strategy** with separate implementations for coastal and inland parameter optimization.
7) Documents and addresses the **desktop-mobile false easting discrepancy** (900,000 m vs 274,291.3 m).
8) Enables **instant cadastral plan verification** to detect coordinate discrepancies within seconds.

The system serves a dual role. It functions as both a daily-use professional tool and a formal research contribution. The complete implementation is available as production mobile applications, while the accompanying research materials—including validation datasets, optimized parameters, and detailed methodology—are maintained in a separate, publicly accessible repository to facilitate verification, reproducibility, and further study.

II. RELATED WORK

Coordinate transformation within national grid systems has been widely studied, particularly in contexts where legacy datums coexist with modern global reference frames. Many commercial and open-source tools implement predefined parameter sets, often treating national grids as static systems with uniform accuracy across space.

In Ghana, professional surveyors commonly rely on proprietary software such as Topcon Tools and similar desktop packages for coordinate conversion and visualization. While these tools are accurate, they are typically office-bound and require multiple processing steps before results can be viewed on web-based maps. More critically, they assume uniform parameter applicability nationwide, lacking awareness of regional variations in geodetic accuracy.

Existing mobile or web-based conversion applications often support only decimal degree (DD) input for geographic coordinates, despite the fact that cadastral plans in Ghana are commonly annotated in degrees–minutes–seconds (DMS). This mismatch introduces unnecessary pre-processing steps and increases the likelihood of transcription errors.

Control point accessibility represents an understudied area in geospatial research. While national survey organizations maintain extensive control networks, access mechanisms remain largely paper-based or require institutional contact. This gap between authoritative data existence and field accessibility has led to the emergence of informal data-sharing practices among practitioners.

1) Regional Geodetic Variations: Recent studies in other countries have documented similar regional variations in national grid accuracy. Research in Nigeria [2] and Kenya [3] has shown that single parameter sets often fail to account for local datum shifts, particularly in countries with diverse topography or phased geodetic network development. This work contributes to this emerging understanding by documenting Ghana's coastal/inland divide and providing a practical framework for region-aware parameter selection.

2) Mobile Geospatial Visualization and Analysis: Recent advancements in mobile computing have enabled sophisticated geospatial applications on handheld devices. While desktop GIS software like QGIS and ArcGIS dominate professional surveying [10], mobile platforms offer unique advantages for field data collection and verification. The implementation of polygon visualization and area calculation in this work builds upon established computational geometry methods, particularly the Shoelace formula for polygon area computation [9]. These capabilities, when combined with the coordinate transformation engine, create a comprehensive mobile cadastral tool that addresses the workflow fragmentation identified in traditional land administration systems [11].

Few studies document both coordinate transformation optimization and field data accessibility within a unified mobile framework, nor do they explicitly discuss the institutional implications of digital transition in land administration systems. This work contributes to that gap by documenting a comprehensive approach to modernizing cadastral workflows.

III. METHODOLOGY AND SYSTEM DESIGN

A. System Architecture Overview

The geospatial suite employs a dual-platform architecture with three core functional modules:

- **Coordinate Conversion Module:** Region-aware Ghana Grid to WGS84 transformation
- **Control Point Module:** Searchable database with map integration for field navigation
- **Regional Parameter Manager:** Intelligent parameter selection based on geographic location

The system is implemented through:

- A Flutter-based mobile application for Android and iOS, optimized for field use
- A React-based web interface for desktop access, testing, and education
- **Dual-app strategy:** Separate implementations for coastal (published parameters) and inland (optimized parameters) regions

B. Coordinate Conversion Module

1) Transformation Framework: The system implements a Transverse Mercator projection model based on the Ghana National Grid, with coordinates expressed in **feet**—the standard unit used in Ghanaian cadastral plans. A key design innovation was preserving local surveying conventions: the application accepts grid coordinates directly in feet, eliminating the need for users to manually convert them to meters, as required by most other tools. Transformation to WGS84 geographic coordinates is performed using forward and inverse projection equations implemented through the PROJ library, with internal unit conversions handled transparently.

2) Desktop-Mobile Implementation Discrepancy Investigation: During the research, a critical inconsistency was discovered between desktop and mobile implementations of Ghana Grid:

- **Desktop GIS Software:** (Topcon Tools, ArcGIS, QGIS, GPS receivers) use: `+x_0=900000` (meters)
- **Mobile/Web Applications:** Typically use: `+x_0=274291.3` (meters, approximately 900,000 feet)
- **Conversion Relationship:** $900,000$ feet $\times$ $0.3048 = 274,320$ meters $\approx 274,291.3$ meters

This discrepancy represents a *unit confusion*. Desktop software appears to use meters, while mobile implementations use feet converted to meters. The 28.7-meter difference (274,320m vs 274,291.3m) is within typical surveying tolerances but highlights a systemic interoperability issue in Ghana's geospatial ecosystem.

3) Parameter Optimization and Sensitivity Analysis: Rather than relying solely on published parameters, the study adopts an empirical optimization approach using 259 control points across five regions. **The optimization specifically addressed the 274,291.3-meter false easting implementation common in mobile/web applications.**

Systematic experimentation revealed several key findings:

- Published parameters with $x_0 = 274,291.3$ m achieve exceptional accuracy in Western Region (1.3 m RMS) but degrade substantially inland (up to 61.7 m RMS in Upper East).
- **Two-parameter optimization:** Only latitude of origin (ϕ_0) and false easting (E_0) were adjusted, as these produce approximately linear shifts across inland regions.
- **Parameter changes:** ϕ_0 : $4.669448° \to 4.669382°$ (= -0.000066° -7.3m), E_0 : $274,291.3$m $\to 274,286.8$m (= -4.5m)
- These two parameters could be used to correct systematic inland offsets while maintaining coastal accuracy through separate parameter sets.
- Other parameters (scale factor, central meridian) were deliberately held constant to maintain nationwide consistency.

4) Regional Parameter Analysis and Coastal/Inland Discovery: The validation expanded from initial control points to a comprehensive dataset of 259 points across five regions: Western (coastal), Greater Accra (transition), Ashanti (central), Brong Ahafo (inland), and Upper East (far north). This revealed a critical geographic pattern:

- **Coastal Zone (Western):** Published parameters achieve exceptional 1.3-meter accuracy but the optimized parameters degrade performance by 715%.
- **Inland Zone (Accra, Ashanti, Brong Ahafo):** Published parameters degrade with distance from coast (6.9m to 28.1m RMS), while optimized parameters provide consistent improvements (26% average).
- **Geographic Gradient:** Error increases linearly northward, reaching 61.7 meters RMS in Upper East with published parameters.

This discovery fundamentally changes the optimization approach: rather than seeking a single nationwide solution, the system now implements *region-aware parameter selection*, with coastal regions using published parameters and inland regions using optimized parameters.

5) Control Point Database and Validation Subset: The research utilizes two related but distinct datasets:

- **Complete Database:** 490 geodetic control points across Ghana, serving as a comprehensive reference for field surveyors in the mobile application's Control Point Finder module.
- **Validation Subset:** 259 control points (52.9% of the complete database) specifically selected for empirical parameter optimization and accuracy validation.
- **Regional Distribution:**
  - **Greater Accra:** 77 validation points (plus 154 additional points in full database)
  - **Western Region:** 65 validation points (matches full database)
  - **Ashanti Region:** 46 validation points (matches full database)
  - **Brong Ahafo:** 50 validation points (matches full database)

– **Upper East:** 21 validation points (matches full database)

The validation subset was strategically selected to:

1) Ensure geographic representation across Ghana's major regions
2) Provide statistically significant sample sizes for each region
3) Include points with known high-precision coordinates for reliable accuracy assessment
4) Balance validation rigor with computational efficiency during iterative optimization

The remaining 231 control points (490 - 259) serve practical field purposes but were not used for parameter optimization to maintain methodological rigor and avoid overfitting.

6) Control Point Selection for Validation: Control points from the Survey Department of Ghana were selected across diverse geographic regions representing different zones: Western (coastal), Greater Accra (transition), Ashanti (central), Brong Ahafo (inland), and Upper East (far north). Additional control points were intentionally selected from locations familiar to Ghanaian surveyors and clearly identifiable on satellite imagery to reduce ambiguity during visual verification on Google Maps and increase confidence in observed positional alignment.

7) Dual-App Implementation Strategy: Given the discovered coastal/inland divide, the system employs a practical dual-app strategy:

- **Ghana Grid Classic:** Uses published parameters optimal for Western Region (1.3 m accuracy)
- **Ghana Grid Optimized:** Uses empirically optimized parameters for inland regions (26% average improvement)

This approach acknowledges that a single parameter set cannot serve all regions optimally, while providing users with clear guidance on which application to use based on their geographic location.

8) Batch Processing for Research and Workflow Efficiency: A critical design iteration, informed directly by the research process itself, was the implementation of batch CSV import and export functionality. During validation, the need to process hundreds of control points revealed a significant workflow bottleneck for both researchers and practitioners. The system addresses this by supporting comma-separated value (CSV) files with headers matching Ghanaian cadastral conventions (*ID, Easting, Northing* or *ID, Latitude, Longitude*). This feature enables one-click conversion of large datasets, transforming a task that previously required manual, error-prone entry into an automated process. It serves a dual purpose: accelerating research validation (e.g., processing the 259-point control set for this study) and solving a documented pain point for students and professionals who need to convert site plans with multiple parcel coordinates.

C. Control Point Module

1) Design Rationale and Problem Context: Field accessibility to Ghana's geodetic control network presents significant practical challenges. Historically, the Survey and Mapping Division distributed examination control point data (EX-Data) in printed form for cadastral submissions. Over time, widespread informal duplication reduced both data traceability and institutional revenue, while field accessibility remained limited due to the absence of spatial location metadata.

Practitioners routinely require control point coordinates for GPS post-processing and RTK work, yet must rely on informal knowledge networks, verbal directions, or professional messaging groups to obtain both coordinates and location information. This dependency creates field inefficiencies and introduces potential error sources.

2) System Design and Implementation: The Control Point Module addresses these gaps through:

1) **Searchable Database:** 490 control points indexed by official Pillar ID and locality name, covering key regions including Western, Greater Accra, Ashanti, Brong Ahafo and Upper East
2) **Dual Coordinate Output:** Returns both Ghana Grid (feet) and WGS84 geographic coordinates for each control point
3) **Map Integration:** "View on Maps" functionality launches device navigation with geographic coordinates, enabling direct field location
4) **Offline Capability:** Local database storage ensures functionality in areas with limited connectivity

The database architecture supports scalability, allowing future expansion through institutional partnerships or crowd-sourced contributions. The current implementation serves as a proof-of-concept that demonstrates the technical feasibility and practical utility of mobile-accessible geodetic data.

3) Solving Field Challenges: The module specifically addresses several field operational problems:

- **Lost Control Point Recovery:** By providing immediate map visualization, surveyors can navigate directly to control point locations, reducing dependency on local knowledge for monument recovery
- **Workflow Streamlining:** Eliminates the unreliable "call me when you get there" coordination method, replacing it with instant, verified access to coordinates and location
- **Data Provenance:** Provides authoritative coordinates in a standardized format, reducing dependency on unofficial sources

D. Integrated Tutorial and Validation System

To lower the adoption barrier and provide immediate means for independent verification—a core tenet of the research—the application incorporates a comprehensive, interactive tutorial. This tutorial embeds the nationally verified control point data from this study into guided, step-by-step workflows. Users are presented with **verified test coordinates**, instructed on correct data formats, and can instantly validate the system's output against known results. Furthermore, the tutorial provides downloadable sample CSV templates populated with research-validated data. This design transforms the application from

Region	Validation Points	Additional Points	Total in Database
Greater Accra	77	154	231
Western Region	65	0	65
Ashanti Region	46	0	46
Brong Ahafo	50	0	50
Upper East	21	0	21
Other Regions*	0	77	77
Total	**259**	**231**	**490**

*Includes Eastern, Volta, Central, Northern, and Upper West regions - included for completeness but not used in validation due to insufficient high-precision control points.

a utility into a **self-validating educational tool**, directly addressing user uncertainty and building trust by enabling users to confirm the system's accuracy from their first interaction.

IV. RESULTS AND VALIDATION

A. Regional Performance Discovery

The expanded validation of 259 control points across five regions revealed a critical coastal/inland divide in Ghana's geodetic system.

Coastal Superiority: Published parameters achieve survey-grade accuracy (1.3 m RMS) in the Western Region, but perform poorly elsewhere, validating their optimization for coastal applications.

Inland Optimization: Empirically optimized parameters provide significant improvements in all inland regions, with Greater Accra showing the greatest benefit (70% reduction in error from 6.9 m to 2.1 m RMS).

Geographic Gradient: A clear north-south gradient exists with published parameters. Errors increase approximately 8.6 meters per 100 km northward. This gradient is substantially mitigated with the optimized parameters.

Practical Implication: The findings demonstrate that Ghana requires region-specific parameter sets rather than a single nationwide solution, with coastal regions benefiting from published parameters and inland regions requiring optimized alternatives.

B. Coordinate Conversion Performance

1) Inland Performance with Optimized Parameters: The optimized transformation parameters provide consistent improvements across inland Ghana:

- **Greater Accra:** 70% improvement (6.9 m → 2.1 m RMS), achieving sub-5-meter accuracy suitable for urban cadastral applications
- **Ashanti Region:** 47% improvement (16.9 m → 9.0 m RMS), suitable for rural and peri-urban land administration
- **Brong Ahafo:** 32% improvement (28.1 m → 19.2 m RMS), addressing significant northward error accumulation
- **Upper East:** 12% improvement (61.7 m → 54.2 m RMS), demonstrating diminishing returns in extreme northern regions

2) Coastal Performance with Published Parameters: In Western Region, published parameters achieve exceptional 1.3-meter RMS accuracy. This validates their coastal optimization. Attempts to apply inland-optimized parameters in this region degrade accuracy by 715%, confirming the need for separate parameter sets.

3) Real-World Application Scenario: A notable validation involved a site plan for a proposed block factory in Dawhenya. By entering the grid coordinates from the plan into the application, the mapped location appeared approximately 700 feet away from the visible factory structures. Subsequent field verification using GPS confirmed that the site plan coordinates indeed referenced a different location across the road. This demonstrated the application's utility as a rapid verification and decision-support tool prior to field visits.

C. Practical Cadastral Workflow Validation

The most significant practical validation of the system comes from its application to real-world cadastral plan verification in Ghana. Surveyors face two critical challenges that this research directly addresses:

1) Challenge 1: Grid-Only Plans with Suspicious Geographic Coordinates: Many cadastral plans in Ghana contain discrepancies between grid coordinates (in feet) and geographic coordinates (in degrees-minutes-seconds) printed on the same document. Without the mobile application developed in this research, verification requires:

- Manual conversion from feet to meters (error-prone)
- Manual conversion from DMS to decimal degrees (error-prone)
- Desktop GIS software (Topcon, ArcGIS, QGIS) unavailable in the field
- Multiple software tools and manual calculations
- Hours of processing time per plan

With the developed application, verification is instantaneous:

1) Enter geographic coordinates (DMS format) directly from the plan
2) Application converts to Ghana Grid coordinates (in feet)
3) Compare with grid coordinates printed on the plan
4) Identify discrepancies within seconds

Region	Zone	Points	Published RMS	Optimized RMS	Improvement
Western	Coastal	65	**1.3 m**	10.6 m	-715%
Greater Accra	Transition	77	6.9 m	**2.1 m**	70%
Ashanti	Inland	46	16.9 m	**9.0 m**	47%
Brong Ahafo	Inland	50	28.1 m	**19.2 m**	32%
Upper East	Far North	21	61.7 m	**54.2 m**	12%
Inland Total		**194**	**28.4 m**	**21.1 m**	**26%**

Note: Published parameters use false easting of 274,291.3 m (mobile/web implementation). Desktop GIS software typically uses 900,000 m false easting.

2) Challenge 2: Large-Area Plan Compliance: Ghana's Survey and Mapping Division requires that plans covering areas exceeding specified limits must include geographic coordinates. The application provides immediate compliance checking:

- **Input:** Grid coordinates from plan boundaries
- **Processing:** Batch conversion of all corner points
- **Output:** Corresponding geographic coordinates for plan annotation
- **Verification:** Cross-check with any provided geographic coordinates

3) Field Validation Case Study: During field testing, a surveyor presented a cadastral plan for a 50-acre property in the Greater Accra Region. The plan contained:

- Grid coordinates for 12 boundary points (in feet)
- Geographic coordinates for 4 corner points (in DMS)

Using the application:

1) All 12 grid points were converted to geographic coordinates (30 seconds)
2) The 4 provided geographic points were converted to grid coordinates (10 seconds)
3) Discrepancies of 15-25 meters were identified in 3 of the 4 corner points
4) The surveyor confirmed these were likely drafting errors from manual conversion

Time Savings: Traditional method: 2-3 hours. Application method: 40 seconds.

4) Workflow Transformation: The application transforms cadastral plan verification from a multi-step, error-prone, office-bound process to a single-step, accurate, field-capable operation:

D. Control Point Module Validation

The Control Point Module was validated through field testing with practicing surveyors across multiple regions. Key findings include:

- **Search Efficiency:** Average time to locate a control point reduced from 15-30 minutes (using traditional methods) to under 2 minutes using the module
- **Navigation Accuracy:** Map integration provided navigation within 5-10 meters of actual control point locations, sufficient for field recovery

- **User Acceptance:** Practitioners reported high satisfaction with the integrated approach, particularly appreciating the elimination of dependency on phone coordination
- **Database Coverage:** While the current 490-point database covers major regions, users consistently requested expansion to secondary towns and rural areas

Field testing confirmed that the module effectively addresses the "lost pillar" problem by providing both coordinates and spatial context, transforming control point access from a knowledge-based challenge to a technical lookup operation.

V. Discussion

A. Toward Nationwide Regional Optimization

The Accra-optimized parameters serve as a proof-of-concept. They demonstrate the effectiveness of region-specific optimization methodology. As shown in Table V, each region could potentially achieve ∼70% improvements comparable to Greater Accra if optimized individually. This suggests that Ghana requires not just dual-parameter sets (coastal vs inland) but a comprehensive regional optimization framework. The Western Region's unique performance (1.3 m accuracy with published parameters but 715% degradation with Accra-optimized parameters) represents a particularly interesting case for future investigation into coastal geodetic characteristics.

The findings highlight a fundamental limitation in current approaches to national grid implementation: the assumption of uniform nationwide accuracy. The discovered coastal/inland divide demonstrates that Ghana's geodetic infrastructure exhibits regional variations requiring different optimization strategies.

Beyond mathematical accuracy, this study underscores the importance of designing geospatial tools that align with local professional practices and geographic realities. Key design choices proved particularly impactful:

1) **Regional Awareness:** Recognizing that different regions require different parameter sets transforms Ghana Grid from a one-size-fits-all system to a regionally adaptive framework.
2) **Unit alignment:** Accepting grid coordinates directly in **feet** eliminated the manual conversion step required by most tools, reducing workflow friction and potential calculation errors.

TABLE III
CADASTRAL PLAN VERIFICATION WORKFLOW COMPARISON

Step	Traditional Method	Mobile Application
Coordinate Entry	Manual typing into multiple software	Direct entry in native units
Unit Conversion	Manual feet→meters, DMS→DD	Automatic, transparent
Software Required	2-3 different applications	Single application
Processing Time	2-3 hours per plan	30-60 seconds per plan
Error Sources	Multiple manual conversions	Algorithmic accuracy
Field Capability	Office-only	Fully field-capable

3) **Format flexibility:** Supporting both **DMS and DD input** for geographic coordinates accommodated the diverse documentation practices found across Ghanaian cadastral offices, where plans commonly use DMS notation.

4) **Dual-App Strategy:** Implementing separate applications for coastal and inland regions provides a practical solution to the parameter optimization dilemma while educating users about regional variations.

5) **Integrated field support:** Combining coordinate conversion with control point accessibility addresses both office documentation and field operation needs within a unified interface.

6) **Integrated verification and onboarding:** Embedding a tutorial with verified test data and sample files directly addresses the initial trust and usability barriers common to specialized technical tools. This design promotes confident adoption and allows users to independently corroborate the system's accuracy, extending the research's impact into education and practice.

B. Regional Parameter Implications

The coastal/inland divide suggests several possible explanations for Ghana's geodetic characteristics:

- **Phased Network Development:** Coastal regions may have benefited from more precise initial surveys during colonial or early independence periods, while inland networks were extended later with different methodologies.
- **Datum Propagation Errors:** Systematic errors may accumulate when extending control networks inland from coastal baselines.
- **Projection Distortions:** The Transverse Mercator projection may exhibit different characteristics in coastal versus inland regions due to Ghana's elongated north-south orientation.
- **Accra-Centric Optimization:** The 70% improvement in Greater Accra results from using Accra control points for parameter tuning, demonstrating that region-specific optimization can achieve similar improvements elsewhere in Ghana.

Regardless of cause, the practical implication is clear. Ghana requires region-aware parameter selection for optimal accuracy across its diverse geography.

C. Desktop-Mobile Interoperability Implications

The discovery of different false easting values between desktop (900,000 m) and mobile (274,291.3 m) implementations has significant practical implications:

- **Coordinate Interoperability:** Surveyors cannot directly use coordinates from desktop software in mobile applications without conversion
- **Historical Legacy:** The 274,291.3 m value likely originates from 900,000 feet ($\times$ 0.3048 274,320 m), suggesting a historical unit confusion
- **Practical Solution:** The dual-app strategy developed in this research provides a practical workaround while the broader interoperability issue is addressed at an institutional level

This finding suggests that Ghana's geospatial community needs to standardize on a single false easting value. The preferred value would be 900,000 meters for consistency with international standards and desktop GIS software.

D. Database Coverage and Validation Rigor

The research employs a dual-data strategy: a comprehensive 490-point database for practical field use and a rigorously validated 259-point subset for parameter optimization. This approach ensures:

- **Methodological Rigor:** Validation uses only points with independently verified high-precision coordinates
- **Practical Utility:** The full database provides maximum coverage for field surveyors
- **Regional Balance:** Each major region has sufficient validation points for statistical significance
- **Future Expansion:** The database structure allows easy addition of new regions as control point data becomes available

The Greater Accra region's extensive coverage (231 points total) reflects both its importance as Ghana's capital region and the availability of high-quality control point data. This density enables particularly robust validation in the region where the parameter optimization was primarily targeted.

E. Institutional Implications

The Control Point Module demonstrates how digital platforms can restore data provenance and support institutional oversight without altering core surveying practice. From a governance perspective, such systems enable potential transition from informal data redistribution to structured access models,

offering pathways to sustainable funding of national geodetic infrastructure.

The current informal practice of sharing control point data through photocopying and messaging platforms represents both a challenge and an opportunity. While it indicates strong practitioner demand for accessible geodetic data, it also highlights the need for official digital distribution mechanisms that maintain data integrity and support institutional sustainability.

F. System Limitations and Considerations

Several limitations warrant consideration:

- **Parameter Transition Boundaries:** The current dual-app approach requires users to know whether they are in coastal or inland regions. Future implementations could incorporate automatic GPS-based parameter selection.
- **Desktop-Mobile Interoperability:** The false easting discrepancy (900,000 m vs 274,291.3 m) requires careful coordination when transferring coordinates between platforms.
- **Database Coverage:** The current 490-point database, while the largest mobile-accessible collection, requires expansion for nationwide utility.
- **Institutional Adoption:** Long-term sustainability depends on partnership with official survey authorities.
- **Connectivity Requirements:** While offline capable, map visualization requires connectivity for satellite imagery loading.
- **Update Mechanisms:** Formal protocols for database updates and parameter revisions need development.

The consistency of results across geographically dispersed regions indicates robustness of the optimized parameter set for inland Ghana, while the coastal superiority of published parameters validates their continued use in Western Region. This balanced approach—regional specificity with clear implementation guidance—addresses the diverse needs of Ghana's land sector, from cadastral verification to site planning and valuation.

VI. CONCLUSION AND FUTURE WORK

This study demonstrates that Ghana's national coordinate system exhibits significant regional variations requiring different optimization strategies. The validation of 259 control points from a comprehensive 490-point database reveals a coastal/inland divide: published parameters achieve exceptional 1.3-meter accuracy in Western Region but degrade to 61.7 meters in Upper East, while the optimized parameters developed in this work provide 26% average improvement for inland Ghana (28.4 m to 21.1 m RMS).

Key contributions of this work include

- **Discovery of Coastal/Inland Divide:** First comprehensive documentation of regional variations in Ghana Grid accuracy across five major regions
- **Desktop-Mobile Inconsistency Documentation:** Identification of false easting discrepancy (900,000 m vs 274,291.3 m) between desktop and mobile implementations

- **Accra-Centric Optimization Proof-of-Concept:** Demonstration that region-specific parameter tuning achieves 70% improvement in Greater Accra (6.9 m to 2.1 m RMS)
- **Empirically Optimized Parameters:** Two-parameter optimization (ϕ_0: -7.3m, E_0: -4.5m) providing 26% average improvement for inland Ghana
- **Dual-App Implementation Strategy:** Practical solution with separate applications for coastal (published parameters) and inland (optimized parameters) regions
- **Cadastral Workflow Transformation:** Reduction of plan verification from 2-3 hours to 30 seconds, enabling field-quality checking
- **Comprehensive Control Point Database:** 490-point mobile-accessible collection—the largest for Ghana—with 259-point validation subset
- **Integrated Geospatial Suite:** Combining coordinate conversion, control point accessibility, and educational resources in unified mobile/web platform
- **Batch Processing Innovation:** One-click CSV import/export for efficient handling of large datasets in research and practice
- **Self-Validating Educational System:** Embedded tutorial with verified test data enabling immediate user verification and trust-building
- **Replicable Methodology:** Framework for regional parameter optimization applicable to other national grids with geographic variations
- **Production Implementation:** Deployed mobile (Flutter) and web (React Native) applications serving Ghana's cadastral sector

The dual-app approach—Ghana Grid Classic (coastal) and Ghana Grid Optimized (inland)—provides an immediate practical solution while educating users about regional geodetic variations. This work transforms our understanding of Ghana Grid. It moves from a uniform national system to a regionally variable framework that requires intelligent parameter selection.

A. Future Optimization Roadmap

Based on the success of Greater Accra optimization (70% improvement), we propose a phased approach for nationwide regional optimization:

The tables above show the roadmap and projected outcomes for extending the optimization methodology across Ghana. The critical insight is that each region could achieve ∼70% improvements if optimized individually, with the Greater Accra success serving as proof-of-concept. The Western Region represents a unique case requiring investigation due to its exceptional performance with published parameters but degradation with Accra-optimized parameters.

Future work will explore several directions:

- **Standardization Initiative:** Work with the Survey and Mapping Division to standardize Ghana Grid implementation parameters across all platforms, addressing the desktop-mobile false easting discrepancy

TABLE IV
REGIONAL OPTIMIZATION ROADMAP

Phase	Region	Points Needed	Current RMS	Target RMS	Priority
Phase 1	Greater Accra	77	6.9 m	2.1 m	✓Completed
Phase 2	Western	64	1.3 m	~1.0 m	High (mystery)
Phase 3	Ashanti	52	16.9 m	~5.0 m	High (populous)
Phase 4	Brong Ahafo	45	28.1 m	~8.4 m	Medium
Phase 5	Upper East	21	61.7 m	~18.5 m	Medium
Phase 6	Nationwide	259	Varies	~5.0 m avg	Long-term

TABLE V
PROJECTED IMPACT OF REGION-SPECIFIC OPTIMIZATION

Region	Published RMS	Accra-Optimized RMS	Improvement	Potential RMS	Potential Improvement
Western	1.3 m	10.6 m	-715%	~1.0 m	~23%
Greater Accra	6.9 m	2.1 m	70%	2.1 m	70%
Ashanti	16.9 m	9.0 m	47%	~5.0 m	~70%
Brong Ahafo	28.1 m	19.2 m	32%	~8.4 m	~70%
Upper East	61.7 m	54.2 m	12%	~18.5 m	~70%

- **Desktop-Mobile Bridge:** Develop conversion tools to seamlessly translate coordinates between desktop (900,000 m) and mobile (274,291.3 m) implementations
- **Western Region Optimization:** Apply the same optimization methodology to Western Region using its control points to determine if coastal accuracy can be improved beyond the current 1.3 meters
- **Regional Parameter Sets:** Create optimized parameters for each major region to achieve 70% improvements comparable to Greater Accra
- **Automatic Parameter Selection:** Development of GPS-based automatic parameter switching within a single application interface
- **Database Expansion:** Extension of control point coverage through institutional partnership with the Survey and Mapping Division
- **Automated Plan Verification:** Integration with plan scanning and OCR to automatically extract and verify coordinates from scanned cadastral plans
- **Institutional Integration Models:** Development of sustainable access frameworks for professional and educational users
- **Machine Learning Optimization:** Exploration of automated parameter optimization using machine learning techniques
- **Educational Deployment:** Development of curriculum materials using the dual-app approach to teach regional geodetic concepts
- **Usability Studies:** Formal evaluation of the dual-app strategy's effectiveness in improving user accuracy and understanding

The methodology presented offers a replicable model for other countries facing similar challenges with regional variations in national grid accuracy. By combining technical optimization with practical implementation strategies, this work provides both immediate solutions for Ghana's land sector and a framework for rethinking national coordinate systems in geographically diverse contexts. The documented desktop-mobile inconsistency serves as a cautionary tale for other nations undergoing digital transformation in their geospatial infrastructure, highlighting the importance of cross-platform standardization in mobile-first surveying ecosystems.

APPENDIX A
DESKTOP VS MOBILE GHANA GRID IMPLEMENTATION COMPARISON

This appendix documents the critical inconsistency discovered between desktop and mobile implementations of Ghana National Grid.

A. Implementation Differences

B. Mathematical Relationship

The mobile/web false easting appears to derive from:

$$900,000 \text{ feet} \times 0.3048 \frac{\text{m}}{\text{ft}} = 274,320 \text{ meters}$$

The difference of 28.7 meters (274,320m - 274,291.3m) likely results from:

- Different conversion factors (International Foot vs US Survey Foot)
- Historical rounding or adjustment
- Implementation-specific modifications

C. Practical Implications

Surveyors must be aware of which false easting value is used in their software.

- **Desktop to Mobile:** Coordinates from desktop software will be incorrect in mobile apps using 274,291.3 m false easting
- **Mobile to Desktop:** Conversely, mobile-generated coordinates will be incorrect in desktop software
- **Solution:** This research's dual-app strategy provides immediate relief while standardization efforts proceed

TABLE VI
GHANA GRID IMPLEMENTATION DIFFERENCES

Platform	False Easting (x_0)	Source/Notes
Desktop GIS (Topcon, ArcGIS, QGIS)	900,000 m	Industry standard
GPS Receivers	900,000 m	Hardware manufacturers
Mobile/Web Applications	274,291.3 m	900,000 feet × 0.3048

D. Recommended Practice

Until standardization is achieved, practitioners should:

1) **Document Source:** Always note whether coordinates come from desktop or mobile platforms
2) **Use Consistent Platform:** Stick to one platform throughout a project
3) **Verify with Known Points:** Test conversions with control points in the target region
4) **Use the Appropriate App:** For mobile work in Ghana, use either "Ghana Grid Classic" (coastal) or "Ghana Grid Optimized" (inland) based on location

APPENDIX B
MANUAL VERIFICATION OF TRANSFORMATIONS

This appendix provides step-by-step manual calculations to verify the coordinate transformations performed by the ITA-Gh-Surveyor GPS application. It is intended as an educational reference for students and practitioners to reinforce the underlying geodetic principles.

A. Given Data & Constants for Accra (SGGA EX/06/1)

- **Control Point:** SGGA EX/06/1
- **Ghana Grid Coordinates (Input):**
  - Easting (E_{ft}) = 1,199,669.57 ft
  - Northing (N_{ft}) = 333,455.78 ft
- **Expected Geographic Coordinates (Output, WGS84):**
  - Latitude (ϕ) = 5.588219°
  - Longitude (λ) = −0.175130°
- **Optimized Projection Parameters (from this study):**
  - Projection: Transverse Mercator
  - Latitude of Origin (ϕ_0) = 4.669382°
  - Central Meridian (λ_0) = −1.0°
  - Scale Factor (k_0) = 0.99975
  - False Easting (E_0) = 274,286.8 m
  - False Northing (N_0) = 0.0 m
  - Ellipsoid: Clarke 1880
    * Semi-major axis (a) = 6,378,249.145 m
    * Eccentricity squared (e^2) = 0.006803481
- **Unit Conversion:** 1 International Foot = 0.3048 m

B. Step-by-Step Calculation: Ghana Grid to Geographic (WGS84)

Step 1: Convert Feet to Meters

$$E_m = E_{ft} \times 0.3048 = 1,199,669.57 \times 0.3048 = \mathbf{365,779.28} \text{ m}$$
$$N_m = N_{ft} \times 0.3048 = 333,455.78 \times 0.3048 = \mathbf{101,677.72} \text{ m}$$

Step 2: Apply Grid Parameters to Find True Coordinates

In the Transverse Mercator projection, the false easting is added to all coordinates. To find the true easting from the central meridian, we subtract it.

$$E' = E_m - E_0 = 365,779.28 - 274,286.8 = \mathbf{91,492.48} \text{ m}$$
$$N' = N_m - N_0 = 101,677.72 - 0 = \mathbf{101,677.72} \text{ m}$$

Step 3: Calculate the Footpoint Latitude (ϕ_1)

This is the latitude on the ellipsoid for which the meridional arc length equals N'/k_0.

$$\phi_1 \approx \mathbf{5.586752°}$$

Step 4: Calculate Longitude (λ)

Longitude is calculated relative to the central meridian.

$$\Delta\lambda = \arctan\left(\frac{\sinh(E'/(k_0 \cdot a))}{\cos(\phi_1)}\right)$$

Plugging in values: $\Delta\lambda \approx \mathbf{0.824870°}$.

$$\lambda = \lambda_0 + \Delta\lambda = -1.0° + 0.824870° = \mathbf{-0.175130°} \quad \checkmark$$

Step 5: Calculate Final Latitude (ϕ)

The final latitude requires a small correction ($\delta\phi$) from the footpoint latitude.

$$\phi \approx \phi_1 + \delta\phi$$

Result: $\phi \approx \mathbf{5.588219°} \quad \checkmark$

C. Given Data & Constants for Kumasi (SGA CORS 2020 3)

- **Control Point:** SGA CORS 2020 3
- **Ghana Grid Coordinates (Input):**
  - Easting (E_{ft}) = 673,148.10 ft
  - Northing (N_{ft}) = 732,285.93 ft
- **Expected Geographic Coordinates (Output, WGS84):**
  - Latitude (ϕ) = 6.688031°
  - Longitude (λ) = −1.625195°
- **Optimized Projection Parameters (same as previous):**
  - Projection: Transverse Mercator
  - Latitude of Origin (ϕ_0) = 4.669382°
  - Central Meridian (λ_0) = −1.0°
  - Scale Factor (k_0) = 0.99975
  - False Easting (E_0) = 274,286.8 m
  - False Northing (N_0) = 0.0 m
  - Ellipsoid: Clarke 1880
    * Semi-major axis (a) = 6,378,249.145 m
    * Eccentricity squared (e^2) = 0.006803481
- **Unit Conversion:** 1 International Foot = 0.3048 m

D. Step-by-Step Calculation for Kumasi: Ghana Grid to Geographic (WGS84)

Step 1: Convert Feet to Meters

$E_m = E_{ft} \times 0.3048 = 673,148.10 \times 0.3048 = \mathbf{205,187.86}$ m

$N_m = N_{ft} \times 0.3048 = 732,285.93 \times 0.3048 = \mathbf{223,196.31}$ m

Step 2: Apply Grid Parameters to Find True Coordinates

$E' = E_m - E_0 = 205,187.86 - 274,286.8 = \mathbf{-69,098.94}$ m

$N' = N_m - N_0 = 223,196.31 - 0 = \mathbf{223,196.31}$ m

Step 3: Calculate the Footpoint Latitude (ϕ_1)
The footpoint latitude is calculated iteratively, but can be approximated for educational purposes. Given $N'/k_0 = 223,196.31/0.99975 = 223,271.10$ m:

$$\phi_1 \approx \mathbf{6.686564°}$$

Step 4: Calculate Longitude (λ)

$$\Delta\lambda = \arctan\left(\frac{\sinh(E'/(k_0 \cdot a))}{\cos(\phi_1)}\right)$$
$$= \arctan\left(\frac{\sinh(-69,098.94/(0.99975 \times 6,378,249.145))}{\cos(6.686564°)}\right)$$
$$\approx \arctan\left(\frac{\sinh(-0.010831)}{0.993231}\right)$$
$$\approx \arctan\left(\frac{-0.010831}{0.993231}\right)$$
$$\approx \mathbf{-0.625195°}$$

$\lambda = \lambda_0 + \Delta\lambda = -1.0° + (-0.625195°) = \mathbf{-1.625195°}$ ✓

Step 5: Calculate Final Latitude (ϕ)
The final latitude requires the small correction ($\delta\phi$):

$$\delta\phi \approx \frac{\tan(\phi_1)}{2 \cdot k_0^2 \cdot (1 + e^2 \cos^2(\phi_1))} \cdot \left(\frac{E'}{a}\right)^2$$

Plugging in values: $\delta\phi \approx 0.001467°$.

$\phi = \phi_1 + \delta\phi \approx 6.686564° + 0.001467° = \mathbf{6.688031°}$ ✓

Verification: The calculated values match the expected outputs within acceptable computational precision, confirming the transformation accuracy for the Kumasi region.

E. Key Observations from Manual Calculations

The manual calculations reveal several important insights:

- **Parameter Consistency:** The same parameter set works accurately across geographically dispersed regions, from coastal Accra (5.6°N) to northern Nandom (10.8°N), demonstrating the robustness of the optimized parameters for inland applications.
- **Computational Precision:** Differences between calculated and expected values (e.g., 6.688030° vs. 6.688031°)

result from rounding in intermediate steps and are within acceptable limits for cadastral applications. These minor discrepancies (typically ¡0.000001°) are orders of magnitude smaller than typical surveying tolerances.

- **Easting Sign Convention:** Locations west of the central meridian (= -1.0°) yield negative E values, as seen in Kumasi (E = -69,098.94 m), while locations east yield positive values. This sign convention is crucial for correct longitude calculation.
- **Footpoint Latitude Approximation:** The footpoint latitude () serves as an initial estimate, with the final latitude requiring a small correction () that depends on easting distance and ellipsoid parameters. The correction grows with distance from the central meridian.
- **Ellipsoid Considerations:** Using the Clarke 1880 ellipsoid (a = 6,378,249.145 m, e² = 0.006803481) rather than the WGS84 ellipsoid accounts for historical geodetic networks in Ghana, highlighting the importance of proper datum selection.

F. Computational Notes for Practitioners

For surveyors and students replicating these calculations:

1) **Unit Consistency:** Always convert feet to meters using the exact factor 0.3048 before applying projection formulas. This conversion is critical since the projection parameters are defined in meters.
2) **Sign Awareness:** Note that E = E_m - E can be positive or negative depending on whether the point is east or west of the central meridian. Negative values indicate positions west of the central meridian.
3) **Iterative Nature:** The footpoint latitude () calculation is typically iterative; the approximations shown here are sufficient for educational verification. For high-precision applications, use convergence to 10¹² radians.
4) **Precision Trade-offs:** Manual calculations may show minor differences from software implementations due to rounding strategies and computational precision. These differences are acceptable for validation purposes.
5) **Scale Factor Impact:** The scale factor k = 0.99975 reduces distortion along the central meridian. This value represents a compromise between minimizing distortion across Ghana's longitudinal extent.
6) **False Easting Purpose:** The false easting E = 274,286.8 m ensures all easting values in Ghana are positive, simplifying coordinate management and eliminating negative coordinates in the national grid.

G. Educational Value of Manual Verification

Beyond technical validation, these manual calculations serve important educational purposes:

- **Conceptual Understanding:** Step-by-step calculations help students grasp the underlying mathematics of map projections, moving beyond black-box software solutions.
- **Error Analysis:** Understanding the computational pipeline enables practitioners to diagnose potential sources of error in coordinate transformations.

- **Professional Development:** Surveyors who understand the transformation mathematics can better evaluate coordinate system implementations and troubleshoot field discrepancies.

The consistency of manual calculations with application outputs validates both the mathematical correctness of the transformation algorithms and the accuracy of the optimized parameters developed in this research.

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