Hybrid Networks for Geodetic Data Collection toward Deformation Monitoring

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SUMMARY

One of the primary functions of governments in developing and emerging nations is the expansion of infrastructure. Today, achieving this in a sustainable manner involves making decisions for spatial development based on trends of solid earth deformation. In areas undergoing active movement and deformation, it is imperative that the frames in which spatial data is presented are appropriately designed.

The development of highly accurate deformation models requires vast amounts of data, over long periods. Common problems in SIDS and other developing nations include a lack of operational, reliable CORS and insufficient spatial or temporal sampling of data from any one observation method. Additionally, geodetic surveys are often carried out using traditional surveying techniques. Though accuracies between data obtained using GNSS technology and those acquired during episodic campaigns often differ, it is possible that combining methods when observing a network can be a feasible approach. These hybrid networks once sufficiently maintained, can then be used to develop more accurate models than those attainable using CORS or episodic data alone.

This research aims to develop a method for the integration of traditional surveying and GNSS observations of points within a network designed for use in deformation monitoring. Successful completion will result in a framework for the combination of data from traditional methods and GNSS surveys in future exercises, in addition to potentially providing a means to increase the spatial resolution of existing models of solid earth deformation.

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1. INTRODUCTION

Land surveying is one of the professions integral in spatial development, and the accuracies of positions obtained determine not only the quality of the survey, but also the potential uses of the data obtained. All measurements contain errors due to user error, equipment capabilities, environmental factors, or random errors (Ghilani and Wolf 2012). During data processing, these errors are removed as much as possible, but the true value of a measured quantity is never known. Hence, positions are always expressed with corresponding uncertainties, which are used in quality assessments. In addition to the errors present in the measuring system, if the area surveyed is actively deforming and there is no available deformation model, the quality of the survey declines with time.

Monitoring surface deformation is seen to be integral to sustainable development and can be achieved through area-specific observation schemes of geodetic networks. These points on the earth's surface are observed to collect input data for the computational processes, in addition to being used to provide control for domestic surveying activities, and the definition of geodetic datums. The geodetic networks used in deformation studies may be passive, with observations made at regular intervals, or active, being observed continuously over extended periods of time (Torge and Muller 2012). Acceptable spatial data collection procedures can employ traditional terrestrial surveying practices, which treat horizontal and vertical components of positions separately, or modern, space geodetic techniques, which provide three-dimensional data. GNSS surveying is one of the more efficient methods of collecting data for deformation studies, as it reduces the physical and temporal demands of the process, and static GNSS surveying is largely independent of environmental factors and most sources of error applicable to traditional surveying methods (Erol, Erol and Ayan 2004). Using traditional and modern survey data collection methods together increases the robustness of any models developed, as the combination increases the redundancy in the system, which can often be an issue in emerging nations and territories.

Models developed from surface deformation studies can represent movement due to geodynamics, or movement as a result of human activity (Kierulf, et al. 2019). Modelling deformation caused by geodynamics requires a significant archive of data, both temporally and spatially, and robust interpolation methods are used in their development (Shariff, et al. 2017). In addition to the method being used to model any deformation taking place, there should be consideration for factors relevant to the intended durability of the model such as error thresholds and temporal changes in deformation (Blick, et al. 2005).

2. DATA ACQUISITION TECHNIQUES

Data acquisition techniques employed by surveyors for deformation monitoring can vary based on factors such as existing infrastructure, available equipment, and intended use. These techniques can range from aerial and terrestrial laser scanning and remote sensing to traditional and GNSS surveying. Depending on the level of development of the territory being surveyed, there may not be sufficient operational GNSS CORS to cover the entire survey area, satellite-based remote sensing platforms may not collect data regularly, and vehicle-mounted remote sensing platforms may not be available.

Whether the data being collected is to be used to monitor deformation on a national or local scale informs the resolution at which it should be collected. Where available, networks of CORS used to provide active geodetic control are preferred. Accuracies of positional solutions using GNSS can be affected by discrepancies in receiver and satellite clocks, atmospheric effects on the transmitted signal, receiver noise, and environmental effects resulting in multipath. Most of these sources of error can be eliminated through relative positioning, which utilizes networks of control for the derivation of solutions, and a sufficiently long observation period allows for the discarding of invalid data, if necessary. The amount of data that can be collected using CORS allows for the analysis of seasonal deformation trends that may not be present in campaign data. However, in emerging nations, it is not uncommon for these stations to be unreliable, or to have been installed recently, and for their and associated archives to contain insufficient data for thorough analysis.

For the spatial densification of GPS data nationally, static observations can be employed, with positions being computed relative to national CORS. While the fast-static observation and processing method is acceptable for regular positioning exercises, it is unsuitable for obtaining positions at the accuracy required for geodetic deformation monitoring. In the absence of portable GNSS receivers, traditional field methods such as triangulation, trilateration, and traversing may be used instead. A significant challenge with the collection of data from passive geodetic networks is keeping up with regular episodic campaigns for data collection, resulting in less than adequate temporal (and often also spatial) sampling.

However, with all surveying activities making use of geodetic control, it is likely that, for any given point in a passive network, even if the local surveying authority has not observed the mark in an extended period, private surveyors or other geospatial professionals may have usable positional solutions. This data, understandably, cannot be directly integrated into an archive of existing geodetic data without proper consideration for the collection and processing methods, and the effects on the quality of the position compared to conventionally collected geodetic data.

3. GEODETIC DATA PROCESSING

Geodetic data processing is conducted in three stages, regardless of whether active or passive collection methods were used. Data is pre-processed, then post-processed, before being analyzed. Pre-processing involves preliminary quality checking, where obviously problematic data is discarded. Sampling is also performed at this stage, but usually observation intervals for static observations are defined before logging data on campaigns, and when downloading data from CORS, users can select the interval suitable for the intended post-processing platform.

Post-processing platforms exist in three main forms: online platforms like AUSPOS and OPUS, proprietary software from manufacturers, such as Trimble's Business Center and Leica's Infinity, and research-grade software, such as GAMIT and GipsyX. Online platforms usually have restrictions on the number of files that can be processed at the same time, and users have no control over the network of reference stations used. Additionally, these platforms often do not clearly state how positional uncertainties are computed, making the process irreproducible. For regular surveying exercises, manufacturer software is sufficient, and users have significantly more control over the post-processing method, with a user-friendly GUI. Due to the variety of proprietary software on the market, if geodetic data is to be crowd-sourced, raw data must also be obtained. Research-level post-processing software allows for the consideration of more factors in data processing, such as atmospheric and tidal modelling, but in a network covering a small region, these effects are generally negligible. With this software, there is a much steeper learning curve than with manufacturer software but in addition to positional solutions, there is often also an option to perform velocity modelling.

3.1 Attainable Accuracies

Figure 1*: CORS in parts of Latin America and the Caribbean (United States National Geodetic Survey 2022)*

Regardless of the post-processing method to be applied, the geometry of the processing network can have significant impacts on the accuracies of positions obtained. With geodetic networks, surveyors only have so much control over the geometry of their processing networks, especially if international CORS are to be used. For example, due to the geography of the Caribbean region, there are no CORS directly to the East of most of the nations to which there are short enough baselines to make inclusion in processing networks even remotely feasible (see **Figure 1**). It is therefore accepted that in this region, positonal uncertainties are likely to be slightly larger in the East than in the North.

In addition to network geometry, the qualities of positions obtained using GNSS are directly affected by the length of the observation period. As shown in **Table 1** below, static observations of up to 4 hours tend to be between 6 to 8 times less accurate than those obtained from 24h data from CORS. It is shown that uncertainties decrease significantly between 4 and 24 hours of data, and this is likely regardless of whether the observations are continuous or from a combination of observation sessions.

***Table 1**: Example uncertainties of data from GNSS Surveys performed in 2022 in Trinidad and Tobago*

Station	Type of control	σN (mm)	σE (mm)	σU (mm)	Length of Observation (hours)
CN57	Active	1.350	1.940	6.310	24
TTSF		1.560	2.140	6.970	
TTUW		1.320	1.880	5.960	
CATH	Passive	9.690	12.320	69.250	4
GASP		5.670	6.960	26.300	
FPRT		6.210	7.800	27.290	
MNLA		7.300	8.120	35.190	
LIRO		5.350	6.490	23.040	

By comparing the results from data acquired over 24 hours vs 10 days, **Table 2** shows that processing more than 24 hours of continuous data increases positional accuracy in the horizontal components by no more than 1mm. Whether it is necessary for observation sessions, to last this long during episodic campaigns, or whether data should be sourced to cover this much time cumulatively, should be considered in the context of the intended longevity and accuracy of any models derived from the positions.

***Table 2**: Comparison of uncertainties obtained from processing 1 and 10 days of CORS data in Trinidad and Tobago*

Station	24 hours			10 days		
	σN (mm)	σE (mm)	σU (mm)	σN (mm)	σE (mm)	σU (mm)
CN57	1.350	1.940	6.310	0.880	1.120	4.080
TTSF	1.560	2.140	6.970	0.910	1.180	4.120
TTUW	1.320	1.880	5.960	0.840	1.090	3.830

Traditional field methods produce solutions from significantly less observations than GNSS surveying, and in addition to the reduced redundancy, are affected by environmental factors more than modern technology. Factors such as baseline length and instrument line of sight capabilities also have to be considered. It was not feasible to collect data using traditional methods for this study. However, it should be considered that the use of positions obtained via traditional field methods may require a transformation to WGS84, depending on surveying conventions in the project area. If a transformation is required from a traditional datum, the accuracy of the parameters should be considered when determining the quality of the final value.

3.2 Velocity Modelling

For deformation monitoring, analyses are performed initially on post-processing solutions, to determine positions and uncertainties, and then on derived positions, to identify any deformation trends. Velocities can be derived using a weighted regression, with weights being determined using the uncertainties of the positions used. A preliminary assessment of the deformation taking place can be useful in determining the tolerance of the model(s) to be developed. Tolerances can then inform decisions on the total length of data required, as well as the number of observation sessions for episodic campaigns. As shown in **Table 3** below, four 4-hour observation sessions are not sufficient to determine the velocities of points undergoing very slow continuous deformation at an acceptable accuracy.

With the amount of data required for accurate models of slow deformation, if positions are to be obtained from surveyors utilizing fast-static observations of geodetic networks, numerous observation sessions would need to be combined to obtain sufficient data for a given year. The combination of sessions in this manner introduces potential additional receiver errors and setting up errors, which should be accounted for. Despite the possibility of introducing more errors into the model, combining observational data in this manner provides values that would otherwise be unavailable.

***Table 3**: An example of uncertainties of velocities derived from positions of active and passive control*

Station	Type of control	σN (mm)	σE (mm)	σU (mm)	Span of Observation (years)	Number of Epochs
TTSF	Active	0.100	0.110	0.430	16	11
TTUW		0.120	0.130	0.480		
CATH	Passive	2.790	3.400	0	6	4
GASP		1.110	1.340	19.370		
FPRT		1.140	1.400	23.300		
MNLA		1.350	1.480	33.630		
LIRO		1.200	1.420	24.500		

4. INTEGRATION CONSIDERATIONS

Bearing in mind the differences between data collection methods used for episodic GNSS observations, the integration of this data into a geodetic network also containing CORS and traditionally collected data for the purpose of deformation monitoring requires a level of standardization of practices. This stadardization includes both procedures for data collection, such as recommendations for the minimum observation period, the type(s) of data to be collected and storage method to be employed, and procedures for the standardized collection and storage of metadata.

As far as episodic GNSS observation periods, while sessions can be combined to obtain poitions, static observations should be no shorter than two hours and sessions to be combined should be no further apart than two months in slowly deforming regions. Combined static session data should be spliced and a network processing exercise performed, and therefore raw observation and navigation data should be collected and stored on a server dedicatied for use with the geodetic network. Aditionally, a standard booking sheet for metadata collection should be developed, and used throughout the region of study.

5. CONCLUSIONS

In smaller areas, and emerging nations, where traditional surveying methods are still preferred over GNSS surveying, it may not always be easy to obtain positions at accuracies sufficient for use in geodetic work. It is therefore pragmatic, in the interest of making use of as much historical survey data as possible, to attempt to combine data from different sources. Issues with this approach when attempting to integrate datasets include consideration must be made for the possibility of less than stellar accuracies of transformation parameters between the datums used to express final positions from traditional survey exercises. When combining GNSS data, it is possible to utilize data from multiple separate observation sessions to derive geodetic quality positions at a given epoch, and to populate velocity models.

When planning data collection campaigns for velocity modelling exercises, it has been shown that when using GNSS surveying, longer observation sessions and more regular campaigns, sub-millimeter accuracies are attainable. While it is possible to carry out these campaigns using traditional methods only, GNSS observations allow for the derivation of regionally and internationally compatible solutions. If raw data is retained, it can be reprocessed using as many control network configurations as possible and the geodetic data archive becomes more versatile, contributing to the sustainability of the infrastructure.

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BIOGRAPHICAL NOTES

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