ENABLING INNOVATION THROUGH GEODETIC TECHNOLOGIES: A PROVINCIAL PERSPECTIVE

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Geodetic technologies enable the measurement of the size, shape and orientation of the Earth, as well as the variation of these parameters over time. Advances in geodetic technology over the past few decades, particularly relating to Global Navigation Satellite Systems (GNSS), have made access to real-time centimetre-level positioning accuracy commonplace. As spatial position information becomes more critical to human and artificial intelligence decision-making processes, innovation has ensued to leverage that information.

A review of key advances in geodetic technology is provided. Examples of innovations that leverage these technologies are presented. It is concluded that the role of geodetic infrastructure will become increasingly important as the backbone for other innovations and that jurisdictions investing resources in this area will be more likely to realize the potential economic benefits and operational efficiencies it creates.

Les technologies géodésiques permettent de mesurer la taille, la forme et l'orientation de la Terre de même que la variation de ces paramètres au fil du temps. Les progrès accomplis dans le domaine de la technologie géodésique au cours des dernières décennies, particulièrement ceux qui sont reliés au Système mondial de navigation par satellite (GNSS), ont donné accès à une précision courante du positionnement en temps réel de l'ordre du centimètre. Alors que l'information sur la position spatiale devient plus essentielle aux processus décisionnels humain et informatisé (intelligence artificielle), l'innovation s'en est suivie pour tirer parti de cette information.

On examine les principaux progrès en technologie géodésique et on présente des exemples d'innovations qui tirent parti de ces technologies. On conclut que le rôle de l'infrastructure géodésique deviendra de plus en plus important comme principal support à d'autres innovations et que les pays qui investissent des ressources dans ce domaine seront plus susceptibles de réaliser l'efficacité opérationnelle et les avantages économiques potentiels qu'elle crée.

Introduction

Geodesy is the science of accurately measuring and understanding the size and shape of the Earth, its orientation in space and its gravity field. Geodesists are also interested in how these parameters vary over time. The more accurately these values and relationships are known, the better we are able to define position on the Earth [*NOAA* 2016].

Geodesists assign coordinates to features on the Earth's surface that reflect the geometric and physical models that relate them. These features are commonly referred to as geodetic control points or geodetic control monuments, as they "control" or underpin the position of other features for which coordinates are derived. By measuring from these control monuments using surveying instruments, position can be determined. Figure 1 illustrates a traditional geodetic control monument constructed with concrete, rebar and a brass marker.

Figure 1: Geodetic control monument.

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Historically, networks of geodetic control monuments have evolved to realize an underlying coordinate system for topographic and bathymetric mapping. As the need for topographic and bathymetric maps arose, control surveys were performed to establish the mathematical relationships between control monuments. Once coordinates were calculated and assigned to the control monuments by geodesists, surveyors and hydrographers could measure to them so that accurate positions could be transferred to their mapping work. For a thorough discussion on the evolution of Canada's mapping systems, see *McGrath and Sebert* [1999].

In the past, geodetic control monuments were strictly passive infrastructure. They did not generate live data streams from which high accuracy positions could be calculated. Terrestrial observations such as angles, distances and height differences were made to the control monuments to derive relative position.

Evolutions in geodetic technologies have changed the way in which geodetic programs are now delivered. Geodetic control monuments, for example, now actively generate data that can be used to determine high accuracy positions in real-time. Presented is a discussion on how geodetic technologies have evolved to become a core infrastructure, not just in surveying and mapping, but in other industries. Example applications are presented and a discussion on future needs for geodetic resources is also provided.

Figure 2: ACS in Halifax, Nova Scotia.

Advances in Geodetic Technologies

Over the past few decades, several advances in geodetic technologies have had a significant impact on industry. Global Positioning System (GPS) is perhaps the single most important geodetic tool to emerge over the past century. GPS created a space-borne control infrastructure (satellites) from which accurate 3D position can be derived. With the emergence of similar satellite-based navigation systems such as GLONASS and GALILEO, the broader Global Navigation Satellite System (GNSS) term is often used. GNSS is the core technology of many of the developments subsequently described. These developments are divided into two groups: a) GNSS augmentation methodologies, which utilize additional infrastructure to enhance system performance; and b) GNSS enhancement products, which provide supplementary information to exploit the full accuracy potential of GNSS.

A) GNSS Augmentation

1. **Active Control Stations:** Permanent Global Navigation Satellite System (GNSS) stations (Figure 2), known as Active Control Stations (ACSs) (or Continuously Operating Reference Stations (CORS)), allow for Differential GNSS positioning to be performed. Real-time kinematic (RTK) surveying is a differential approach that utilizes live streams of GNSS tracking data from a reference (or "base") station to generate high accuracy corrections applicable within a radius of about 25 km. Horizontal positioning accuracy is typically ±2 cm + 1 ppm (1 mm/km) and vertical positioning accuracy is typically ±3 cm + 1 ppm in real-time. Higher accuracy can be achieved by using longer observation periods for the point of interest.

   In essence, the ACS eliminates the need to have a dedicated surveyor operate a reference station in the field using traditional reference and rover receiver setups. By locating the GNSS equipment in secure locations, it can run continuously so that the Differential GNSS requirement for simultaneous measurements can easily be achieved. The ACS technology makes survey work achievable with fewer human resources.

   ACSs have been implemented by various organizations across the country to leverage the efficiencies they provide, including survey companies, municipalities, provinces, the federal government and GNSS RTK service providers.

2. **Network Real-Time Kinematic (NRTK) GNSS:** GNSS positioning algorithms have

evolved so that by locating ACSs across wider areas, corrections can be modelled and used for Network RTK (NRTK) positioning. By forming a polygon with ACSs, GNSS corrections can be interpolated and the distance dependent positioning error can be reduced from 1 ppm to 0.5 ppm (0.5 mm/km). Using wireless Internet services, these corrections can be broadcast to users in the field. Users require a cell modem or can tether to another Internet-connected device to receive differential corrections. In Canada, the majority of NRTK GNSS services are provided by private industry on a subscription basis. Some private companies that operate over a large region also establish ACS infrastructure and operate the required software and IT infrastructure to provide NRTK services for their own purposes.

3. **Precise Point Positioning:** GNSS positioning algorithms have evolved to provide sub-centimetre positioning accuracy using a single GNSS receiver (Absolute Positioning). The technology utilizes precise satellite ephemeris information estimated using a global GNSS observation network. In recent years, service provision models have evolved rapidly. In Canada, post-mission PPP solutions are now being made available from multiple sources. Access to a global GNSS network to compute PPP corrections implies reliance on open data sharing with other international agencies or partners. Canadian Geodetic Survey's (CGS) Precise Point Positioning (PPP) Service is an example of technology offering this capability in post-mission. Users can submit GNSS observation files and retrieve high accuracy positions within minutes. [*Klatt* 2016]. Academic initiatives also have developed PPP software, such as the University of New Brunswick's GNSS Analysis and Positioning Software (GAPS) [*UNB* 2016] and the University of Calgary's Precise Point Positioning (P3) software [*U of C* 2016].

4. **Real-Time Precise Point Positioning:** Multiple private sector firms, often associated with GNSS equipment manufacturers, now offer real-time precise point positioning services that leverage real-time GNSS data from their proprietary global tracking networks. Accuracies higher than ±4 cm can be obtained in real-time by receiving corrections via satellite or cellular communications [*Trimble* 2016]. Presently, real-time PPP services are mainly provided by private industry.

B. GNSS Enhancement Products

1. **Velocity Model:** The ability to accurately relate coordinates determined at one time period (epoch) with respect to another requires a knowledge of the tectonic movement. Since the 1990s, CGS has been observing geodetic control monuments across Canada with GNSS to determine the velocity model for the country. By modelling the tectonic behaviour of the North American Plate, coordinate relationships can be preserved over time [*Klatt et al.* 2016].

2. **Geoid Model:** The ability to accurately relate orthometric heights measured using GNSS requires a highly accurate, equipotential surface. CGS's efforts to develop the Canadian Geodetic Vertical Datum of 2013 (CGVD2013) has fulfilled this need. The developed geoid model (CGG2013) provides centimetre-level accuracy across Canada. The geoid has been developed using satellite-based gravity measurements [*Klatt et al.* 2016].

Example Innovations

As a direct result of the above advances in geodetic technologies, the following innovations have ensued:

1. **Geodetic Program Modernization, Nova Scotia:** In an effort to develop a sustainable geodetic program, the Province of Nova Scotia implemented a network of ACSs known as the Nova Scotia Active Control Stations (NSACS) network. The NSACS enables real-time positioning accuracies of a few centimetres throughout the province using GNSS NRTK. With this technology, the Province is now able to re-observe and maintain its passive geodetic control network. In the past, observation sessions of 8 hours or more were required to perform coordinate updates. With the new infrastructure, observation sessions have been reduced to 10 minutes and deliver equivalent accuracy [*Bond* 2015a].

   The NSACS infrastructure has also lead to significant operational efficiencies in other provincial programs. Crown surveyors in the Department of Natural Resources have reported operational efficiency increases of 25%–100% on any given day because of the ease at which surveys can be accurately referenced to the Nova Scotia Coordinate Referencing System (NSCRS). Highway construction projects tendered by the Department of Transportation and Infrastructure Renewal are also benefitting from the NSACS. Heavy machinery utilizes corrections from the NSACS to automatically guide their blades to finished grade (Figure 3). On a typical highway construction project, that technology reduces survey costs by 50% or more and increases operational safety.

2. **Cadastral Modernization, Alberta:** In an effort to provide a cost effective mechanism for the disposition of public lands, a Hybrid Cadastre has been implemented. The model uses a blend of monuments and coordinates to define disposition boundaries. A coordinate is treated as a survey marker for the purposes of determining disposition boundaries on public lands. Coordinates can lose their governing status upon replacement by a statutory iron post. At any instant, a coordinate or a physical survey marker can govern a position, but not both. All coordinated points must be determined to 0.100 m absolute accuracy at 95% confidence [*Shrivastava* 2016]. This innovation leverages GNSS, NRTK, PPP and the velocity model to meet accuracy specifications.

Figure 3: Bulldozer leveraging GNSS NRTK for achieving finished grade in Antigonish, Nova Scotia.

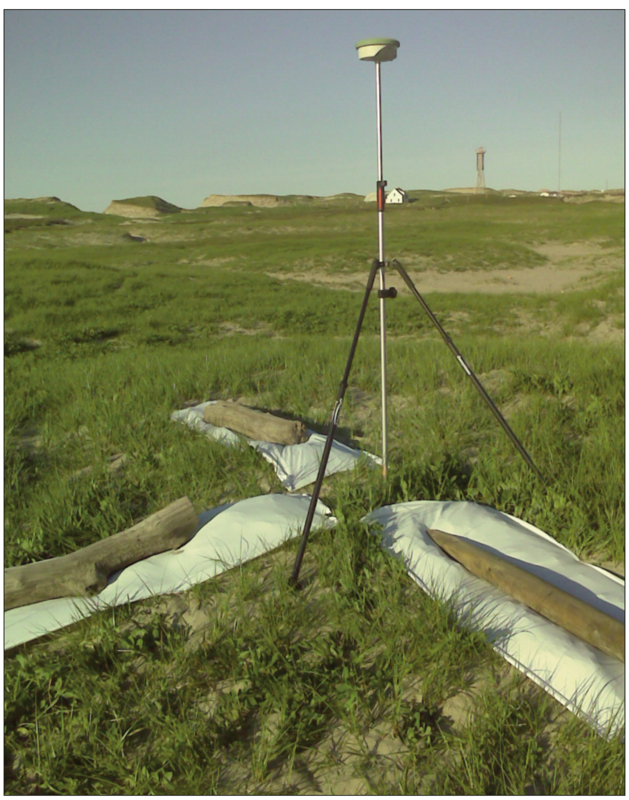

Figure 4: Quality control point positioned using GNSS for aerial photography.

3. **Modernization of Geo-Referencing and Quality Control (QC) Techniques for Aerial Photography, Nova Scotia:** On an annual basis, the Nova Scotia Topographic Database program, in conjunction with the Department of Natural Resources, captures high resolution digital imagery of a section of the province. The imagery must be georeferenced within the provincial coordinate system and data quality controlled for accuracy. In the past, geodetic control monuments would be accentuated with large targets to serve this purpose. Challenges would arise in finding suitable control monuments that were visible from the air and that provided a strong distribution over the area of data collection. Additionally, coordinate values for geodetic control monuments from historic coordinate systems would not necessarily have sufficient accuracy to perform the geo-referencing and QC work. With the implementation of the NSACS network, high accuracy geo-referencing and QC points can be established anywhere convenient within minutes (Figure 4). Significant operational efficiencies have been realized and a higher quality final product is produced.

4. **Precision Agriculture, Canada-Wide:** GNSS NRTK and real-time PPP are being used to drive farming equipment across Canada. The ability to precisely steer tractors using GNSS allows crop rows to be more tightly spaced, generating higher crop yields. Additionally, crop spraying can be better controlled using GNSS technology, saving costs and better protecting crops.

Future Applications

As technology continues to evolve to leverage high accuracy positioning tools, new applications will emerge. Known areas that could benefit from the technology are discussed.

Guaranteed Boundaries

During the late 1970s, the Maritime provinces invested significant funding into developing the Land Registration and Information Service (LRIS). The LRIS was a comprehensive effort to manage property rights, one of the fundamental pillars of modern societies. The ultimate goal of the LRIS program was to create a land registration system that could guarantee boundaries. Through a comprehensive surveying and mapping initiative, boundaries could not only be described by metes and bounds but also be positioned in a coordinate system spanning the Atlantic provinces [*Sebert* 1999]. Although the concept of guaranteed boundaries was not implemented through the LRIS, New Brunswick and Nova Scotia have implemented land titles systems which do provide a guarantee of ownership of registered properties. The land titles system guarantees that land owners have title to a particular parcel, but there is no guarantee as to the size and extent of the property. Similar situations exist in other Canadian provinces.

The high accuracy positioning capabilities of GNSS allow the question of the extent of property rights to be more readily answered and the concept of guaranteed boundaries to be considered. The value of such a proposition is that it brings an unprecedented level of certainty to property rights for a jurisdiction, which contributes to economic stability. A classification system would need to be implemented that builds the integrity of a boundary over time. As repeat surveys confirm the location of that particular boundary, the weight of the boundary would increase towards "Guaranteed." For example, a boundary that has not been confirmed by another survey could be given "Provisional" status. Once a boundary has been independently verified by another survey, the status could become elevated to "Pre-Guaranteed." Finally, upon a third survey confirming a boundary location, its status could become elevated to "Guaranteed" status.

The concept of guaranteed boundaries could be first tested in new subdivisions where the intent of property extent is very clear. Although GNSS facilitates the ability to measure extent, it must be appreciated that the profession of surveying can be as much of an art as a science when interpreting boundary evidence, especially on old parcels where boundary lines date back over several hundreds of years. There are also several implementation questions that would need to be addressed when implementing such a system, including who would bear the liability of a guaranteed boundary and to what accuracy a boundary is guaranteed.

Autonomous Vehicles

Most major automobile manufacturers are devoting significant effort to developing autonomous vehicles. Google has already driven over 1.5 million miles (2.4 million kilometres) with its autonomous vehicle fleet [*Google* 2016]. Light detection and ranging (LiDAR), radio detection and ranging (radar), and digital cameras are some of the technologies employed for autonomous vehicle navigation.

Despite tremendous advances with the technology, snow continues to pose major challenges with these technologies. Snow not only covers the sensors but also makes the detection of lanes next to impossible [*Adaddy* 2016]. High rate, high accuracy GNSS positioning could help alleviate this problem by using a map and match approach. By accurately mapping road locations, GNSS can be used to allow autonomous vehicles to follow existing routes and to stay within lanes even when covered by snow. The approach relies upon geodetic ACS infrastructure to enable RTK or real-time PPP positioning.

Emergency Preparedness

Geodetic technologies are commonly used for long-term deformation monitoring of civil infrastructure, tectonic movements, slopes, steep embankments and other natural features subject to geophysical loading. By analyzing GNSS position trends with millimetre-level accuracy, warnings can be provided when abnormal behaviour occurs. Although the use of geodetic technology for deformation monitoring is not new, the increase in active geodetic infrastructure across Canada and the development of real-time PPP has made GNSS-based deformation monitoring systems easier to implement. Additionally, decreases in the cost of geodetic-quality GNSS receivers are making the technology more accessible for small-scale projects.

Early warning systems for earthquakes are an example of an emergency preparedness technology from which Canada would benefit. The GNSS Earth Observation Network (GEONET) System in Japan consists of 1200 GNSS ACSs throughout the country. Data from the ACSs are streamed in real-time to a processing server for analysis. Unusual displacements of the ACSs are used to signal early warnings of potential earthquakes [*GSI* 2016]. This technology is not commonly used in Canada but would provide value in tectonically active regions. Nova Scotia, Prince Edward Island and sections of British Columbia and Ontario, for example, have in place ACS infrastructure that can be leveraged to detect unusual displacements that may signal an earthquake.

Outlook

The growing importance of spatial information in human and artificial intelligence decision-making processes will increase demands for strong geodetic programs across the country. The value of this background infrastructure is not well understood and this can pose challenges in securing resources for implementing and maintaining it. As geodetic technologies become the foundation for new innovation, those jurisdictions investing in their geodetic programs will have a better chance of benefitting from the economic opportunities that the technology brings.

Despite GNSS facilitating the ability to measure high accuracy coordinates, there will always be a need to relate present coordinate values to historic coordinate systems. These relationships require a strong understanding of geodesy to transform coordinate values between different datum and different epochs. The science of geodesy cannot be ignored in trying to achieve the millimetre-level accuracy positioning requirements for complex engineering projects. It will continue to be important to invest in geodetic expertise to provide industry with the tools and applications that it needs to capitalize on the value of high accuracy spatial information.

Summary

Over the past few decades there have been several key advances in geodetic technology, including GNSS, ACSs, NRTK, PPP, gravimetric geoid modelling and velocity modelling of tectonic motion. The evolution of the technology is allowing for real-time access to high accuracy position information. Geodetic technology is being leveraged for machine automation applications such as precision agriculture and highway construction, emergency preparedness, boundary surveys and cadastral system modernization. The role of geodetic infrastructure will become increasingly important over time as it serves as the backbone for other positioning technologies and innovations.

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