Global Position System (GPS) for Safeguards Applications

G. A. Borstad[1] and Q.S. Bob Truong[2]
[1]Borstad Associates Ltd., Sidney, British Columbia, Canada
[2]Canadian Nuclear Safety Commission (CNSC), Ottawa, Canada

ABSTRACT
Verification of State Declarations requires a good knowledge of the location of facilities. Planning and conduct of on-site inspections requires accurate maps, the ability to navigate to and from sites, and to track where the inspector has been. The recent revolution in satellite based navigation and positioning stimulated by the American Global Positioning System (GPS) provides inexpensive location, navigation, tracking, mapping and timing information 24 hrs a day, everywhere around the world. Originally designed as a military navigation system, GPS has come into widespread use for commercial and civilian use. There were approximately 143 million GPS units in existence in 2006 and more than 5 million units will be added in 2007. With these volumes come an increasing number of suppliers, rapidly increasing capabilities, decreasing size and cost, and many new applications. This paper briefly reviews the operation of the GPS system and its history, references some important practical uses such as tracking of vehicles or containers containing nuclear material, and provides an annotated reference list of websites providing free or low cost maps and relevant software. An example illustrating the application of GPS and a simple custom map to relevant location, navigation, tracking and mapping tasks is intended to serve as a useful introduction to inspectors and others who do not have hands-on experience with GPS navigation.

INTRODUCTION
Positioning oneself on the surface of the globe has been very important for many kinds of endeavor since before humans came down out of the trees. It has always been relatively difficult to do, and the object of much attention – particularly by the military, where knowledge of ones position has critical strategic and tactical advantage. The military developed land-based radio-navigation during the 1940s and these were replaced in the 1970s by early versions of the US Global Positioning System (GPS). The GPS is a satellite-based navigation system that provides all weather, global geo-positioning 24 hours a day, using small autonomous receivers that accurately determine their latitude, longitude and altitude using very precise time signals transmitted from a series of satellites.

The US Department of Defence now has a huge investment (estimated at $22 billion 1995 dollars) in the NAVSTAR Global Positioning System (GPS). GPS consists of a constellation of 27 satellites that produce the positioning signals; control and monitoring ground stations, plus data links with the associated command and control facilities. Originally restricted to military use, the GPS system was declassified for global public use following the Korean Air Lines 007 air disaster in 1983, where poor navigation led to increased cold-war tensions. A detailed history of the GPS system is available at several websites [eg. 1]. An annotated glossary of GPS terms is also available [2]. The GPS is currently managed by a committee of the US government that manages the system "consistent with national policy, to support and enhance U.S. economic competitiveness and productivity while protecting national security and foreign policy interests". For this reason, several other countries (Russia, Europe, China, India) are planning to implement their own systems

OPERATION OF THE GLOBAL POSITIONING SYSTEM

There are many detailed descriptions of the operation of the GPS system available [1,2]. Briefly, a small GPS receiver calculates its position on the earth's surface by measuring the distance between itself and three or more orbiting GPS satellites. By determining the position of and distance to the satellites, the receiver can calculate its position on the globe by triangulation. Without further augmentation, the present accuracy of the calculated position for civilian receivers is between 5 and 15m. The position accuracy depends on factors such as the relative position of satellites in the sky overhead, ionospheric interference, tropospheric humidity effects, reflection of signals off surrounding terrain and buildings and clock errors. The GPS system as originally declassified provided positions degraded to about 30m through a feature called Selective Availability (SA) that intentionally introduced slowly changing random errors up to 100m. Military receivers always had the capability to circumvent SA, and civilian users soon discovered that one could correct the position of one receiver relative to another stationary one nearby through a process called Differential Correction. SA was turned off in 2000, and is unlikely to be turned on again because the US now has 'regional denial capabilities' [3].

There are many improvements and augmentations to the civilian GPS that use external information to make more precise positioning – either by using more precise measurement of the sources of error, by comparing measurement of a moving receiver to a stationary one (Differential Correction), or by merging the GPS location data with that from an inertial navigation system. Some of these improvements come as standard equipment on the mid and high end GPS receivers. Others will be implemented by the US in the coming years [4].

THE MAIN APPLICATIONS OF GPS

Location: All GPS receivers quickly *determine their geographic position, location and elevation*. The cheapest receivers interrogate fewer satellites than the more expensive ones, so the positions are not as accurate. There are many ways to improve the location accuracy, down to millimetres in the extreme case for some scientific applications.

Navigation: All but the low-end receivers also find the *most efficient route* from one location to another along road networks, usually with a combination of a suggested track, audio prompts and text instructions. The more expensive car navigation units also provide human voice prompts. The user enters a desired destination location and the receiver suggests a route consistent with a number of constraints selected by the user (shortest route, shortest time, avoid freeways, avoid unpaved roads, etc). This requires the receiver to be loaded with a detailed digital map of the area of interest. Very detailed road and topographic maps of most areas in North America an Europe are available for purchase from the GPS manufacturers, but other companies and even individuals are also producing excellent GPS compatible maps that are made freely available. Simple software is also available for the user to make customized maps.

Tracking: Mid and upper end receivers also show the present location and *the route taken to get there*. Note that many car navigation units will not save the track for export to GIS or to other devices. Also monitoring the movement of people and things (GPS used in conjunction with communication devices).

Mapping: Using saved locations or tracks from mid and upper end receivers, one can export geographic data to Geographic Information Systems to *quickly and easily create custom maps*. With differential GPS, time averaging or several other augmentations, positions can be recorded to within millimetres). A single surveyor can work uninterrupted in periods of poor weather conditions or reduced sunlight, to accomplish in a day what used to take a team of 2 or 3 surveyors days or weeks. There are many Geographic Information Systems (GIS) available in which to build customized maps that either use (or are derived from) GPS data and collated with geo-located satellite imagery. QuantumGIS is an example of a simple but capable shareware GIS program. At the upper end, the IAEA uses a professional version of ARCMap.

Timing: Since GPS is based on precise timing, it can be used for time transfer and synchronization anywhere in the world.

Other non-geographic uses: Manufacturers are trying to differentiate consumer grade GPS units by adding many other non-geographic applications for 'everyman'. Hand held units now often include electronic compass, sunrise, sunset, calendars, calculators, best fishing times, tide tables, barometric pressure tracking, two-way radios. Many in-car navigators have built in maps, touch screen operation, voice prompts in more than 35 languages, blue tooth cell-phone, traffic alert services, 'buddy-finder' via instant messaging, satellite radio, remote control, mp3 players, photo-viewers, calculators, travel clock, and currency converters. There are also a wide variety of speciality GPS units designed for truck drivers, boaters, pilots, motorcyclists, runners and hunters that are fully integrated with phones, laptops, PDAs, watches, chart plotters, radar, sounders, radio, heart rate monitors, and even dog collars.

GPS IN SAFEGUARDS

Inspections: Most Safeguards inspections are routine, cooperative exercises as part of the verification of states declarations. Local personnel guide the inspectors on their visit, and it could perhaps be argued that the inspectors do not need to know precisely where they are. However, in large sites with many buildings or complicated road networks such as mines, having one's own customized dynamic maps that are independent of the local operator might be quite useful.

Many national inspection agencies have agreements with their licensees, or bilateral agreements with neighbouring states to allow GPS and other devices inside the gate of their nuclear facilities. Other states do not allow inspectors to bring electronic equipment such as GPS onto their sites. Even for these inspections, GPS can be used to check the location of the front gate (in itself a very useful reference location), to help the inspectors navigate around a new city, document where they have been, and to orient the site with respect to the airport, the city and the hotel.

The most commonly permitted activities under international inspection are visual observation, collection of environmental samples, and utilization of radiation or measurement devices. GPS can provide the geo-position of these observations or measurements, and the means to precisely locate them on satellite imagery or in a GIS. The IAEA has prepared an inspection toolkit that includes GPS to assist inspectors on their mission. However, from discussions with inspectors, we understand that GPS is not yet in common usage.

SOME USEFUL GPS RELATED SOFTWARE AND INFORMATION

QuantumGIS (http://qgis.org/) is a simple Open Source Geographic Information System for several operating systems, used to prepare the example maps for this paper. It supports vector, raster and database formats allowing the user to browse and create maps. ***GPSMapEdit*** found at (http://www.geopainting.com/en/) is a Graphic User Interface for the Windows and Linux program ***cGPSmapper*** (http://cgpsmapper.com/) used to create the vector maps in Figure 1 for Garmin GPS receivers. ***SendMap*** is a companion program at the same site for uploading custom maps to the Garmin receiver. This site also provides more than 115 custom maps produced by individuals for countries without access to commercial maps.

MobileMapperOffice (MMO) at (http://www.msh-tools.com/magellanmapseng.html) provides similar tools to produce custom vector maps for Magellan GPS receivers. There are several other inexpensive software packages for GPS mapping, downloading and combining maps and images, visualizing GPS data, and geo-referencing digital photographs using their EXIF time stamps. Some Windows examples are: ***GPSTrackmaker*** (http://www.gpstm.com/) - a freeware Windows program to create, edit and exchange Tracklogs, Routes and Waypoints with a Garmin GPS. Many maps for Africa and South America are available at this site. ***Topofusion*** (http://www.topofusion.com), ***Robogeo*** (http://www.robogeo.com/home/), ***Mapwel*** (http://mapwel.biz/index.htm) ***Jetphoto*** (http://www.jetphotosoft.com /web/home/) all provide the capability to organize and geo-reference photos ***GPSPhotolinker*** (http://oregonstate.edu/~earlyj/gpsphotolinker/) is a MacOS program.

AN EXAMPLE OF A SIMPLE CUSTOM-MADE MAP

Commercial GPS maps with good road coverage for public areas are available for North America, Western Europe, Japan and some other countries. Maps for many smaller countries are available from groups and individuals online (as mentioned in the previous section). In all commercial maps, only the road network is shown, with simple waypoint symbols shown for points of interest – as in Figure 1A (eg. gas stations, hospitals, restaurants, museums, car rental agencies). Buildings themselves are not shown. A custom map of the same area is shown in Figure 1B - D.

It is not difficult to make an additional, custom map of, say a particular facility, showing labeled gates, internal roads and buildings to assist in an inspection. Figure 2 shows the steps in making the GPS map in Figure 1, in this example an area referred to as 'West Camp' (on the Victoria International Airport, Victoria, BC, Canada). A geo-located digital aerial photograph (or high resolution satellite imagery) was loaded into *QuantumGIS* (or any other GIS), and used as a base-map for digitization of the buildings and roads (Figure 2B). The map produced was saved as a .shp file. The .shp file was then converted to an img file using *GPSMapEdit*, and uploaded to a Garmin GPS 76CSx using *SendMap*. The final map as seen in the GIS is in Figure 2B, on the GPS is shown in Figures 1B-D.

SOME USEFUL THINGS TO KNOW WHEN USING A GPS

Position Accuracy: The position accuracy depends on the receiver and local conditions. Most GPS receivers show the expected accuracy of the reported position for a waypoint. Averaging over a few minutes will increase the accuracy of the position.

Unobstructed view of the sky: The GPS receiver must have an unobstructed view of the entire sky. Most receivers show the distribution and availability of satellites in view. The receiver must have at least 3 satellites well separated in the sky in order to navigate properly. More, and widely spaced satellites will ensure a more accurate position. Satellites that are low on the horizon, or are blocked by trees or buildings will not be accessible.

A B C D

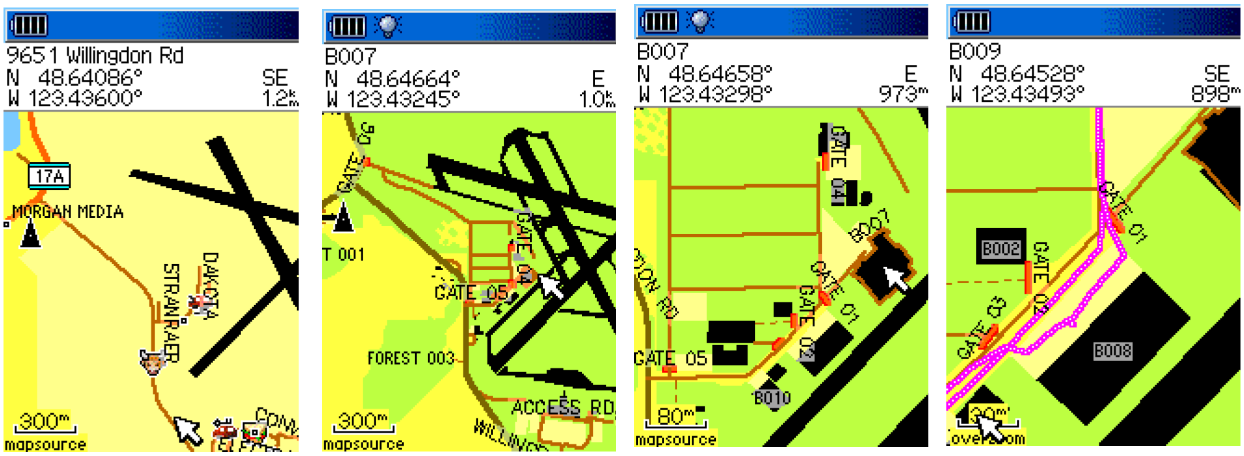

Figure 1. (**A**). The most detailed commerical map avilable from Garmin for the Westcamp area. (**B**). A more detailed custom map produced here. (**C** and **D**). Enlargements of the customized map, showing gate, road and building labels. **D** also shows the GPS track in which the car entered the parking lot near building 008.

A B

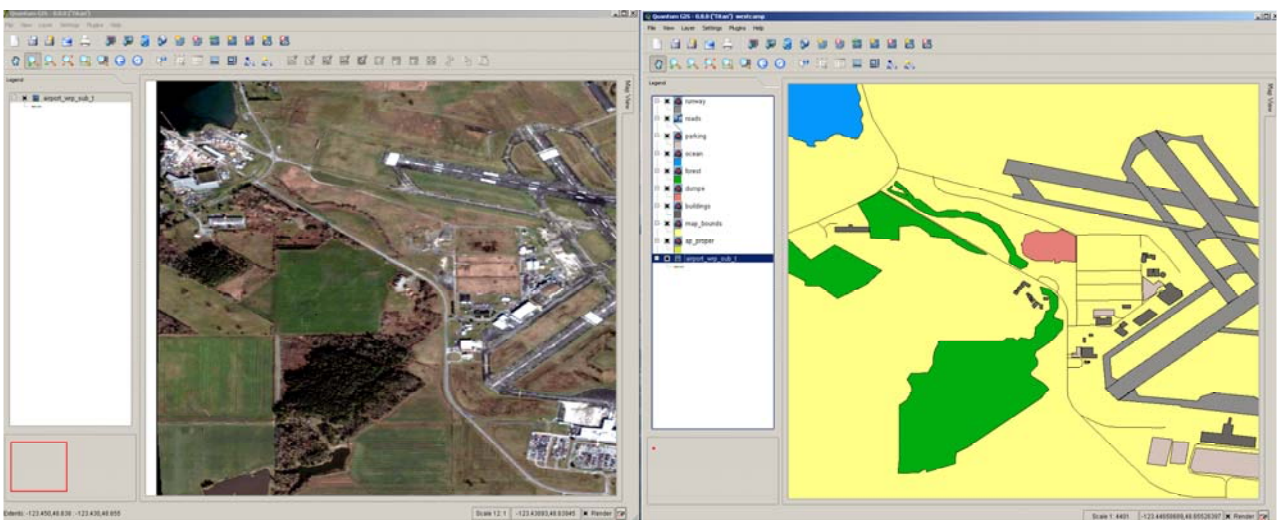

Figure 2. Custom map creation, beginning with a high-resolution aerial photo or satellite image (**A**) and the map after digitization in Quantum GIS (**B**).

Positioning near buildings: It is difficult to obtain a reliable position near a building, since the sky will be partially obscured, and the receiver may be getting a signal reflected from the building. It is best to take a reference position away from the building and measure the distance to the corner, or transfer the measured position to a satellite image later.

Timing information: Each GPS position in the track (pink line in Figure 1D) is made with a precise time that can later be used to position photographs, measurements or visual observations. User defined Waypoints can be created with a push of a button on the GPS receiver. Software exists to automatically geo-reference photographs.

CONCLUDING REMARKS

The intent of this paper is to provide a brief introduction to GPS for inspectors and others at the IAEA (and other similar inspection agencies) who may have use for reliable geo-location, and to demonstrate that custom-made maps synchronized with a conventional digital camera or other measurements can easily be prepared as an effective and efficient inspection tool for inspectors.

GPS is presently accurate to 3-5m anywhere and any time, to within cm with Differential Correction. Because GPS receivers are becoming very inexpensive and much smaller, they are beginning to appear in many kinds of consumer electronics (cell phones, cameras, PDAs, watches, cars) and dedicated instruments. Many new applications are developing. Other improvements are coming soon, including higher accuracy, reduced interference, faster acquisition, miniaturization of receivers, interoperability with satellite navigation systems from other nations beginning 2013, and perhaps even indoor use.

ACKNOWLEDGMENT

The authors would like to thank Peter Willis of Borstad Associates Ltd. for his excellent technical assistance in the preparation of this paper.

REFERENCES

1. Pace, S., G. P. Frost. I. Lachow, D. R. Frelinger, D. Fossum, D. Wassem and M. M. Pinto. “The Global Positioning System, Assessing National Policies. Appendix B: GPS History, chronology and budgets.” RAND Corporation Monograph MR614, 1995. Accessed 2007 at http://www.rand.org/pubs/monograph_reports/MR614/

2. Trimble. “GPS Tutorial. How it Works.” Accessed 2007 at http://www.trimble.com/gps/howgps.shtml

3. GPS and Selective Availability. National Geodetic Survey, NOAA briefing. Accessed 2007 at http://www.ngs.noaa.gov/FGCS/info/sans_SA/docs/GPS_SA_Event_Talking_Points.pdf

4. NASA. “GPS Augmentation & Other Networks”. 2007. Accessed 2007 at http://gpshome.ssc.nasa.gov/default.aspx