Reference Data Set for Performance Evaluation of MEMS-based Integrated Navigation Solutions

Charles TOTH, Dorota BRZEZINSKA, USA
Nonie POLITI, Allison KEALY, Australia

Key words: MEMS sensors, performance validation

SUMMARY

The development of MEMS Inertial Measurement Sensors (IMU) has shown steady progress in recent years; there is a measurable increase in the number of sensors on the market, and, most importantly, the performance is also improving after years of stagnation. Though manufacturers provide sensor characterization information, the lack of standardized, generally accepted parameters makes any performance comparison difficult. Therefore, the need for experimental comparison still exists. To support academic research, mainly in navigation algorithmic developments, a collaborative working group across the professional institutions of the International Association of geodesy (IAG) and the International Federation of Surveyors (FIG) was formed and a series of field tests were carried out using a representative sample of MEMS sensors. For reference purpose, navigation-grade IMUs were also included in the tests, so a highly accurate baseline solution is available. This paper describes the sensor configuration, the mobile surveys conducted, and the reference and MEMS measurement data that are now available to the navigation and surveying community.

Reference Data Set for Performance Evaluation of MEMS-based Integrated Navigation Solutions

Charles TOTH, Dorota BRZEZINSKA, USA
Nonie POLITI, Allison KEALY, Australia

1. INTRODUCTION

Due to recent technological advancements, MEMS sensors are increasingly becoming available in a growing number of applications. However, their still modest performance, primarily characterized by large drift and noisy sensor measurements, presents challenges to the navigation community; in particular, as most of the Extended Kalman filter-based navigation solutions are customized toward using navigation- or tactical-grade IMUs. In addition, there are non-conventional sensors, such as ranging and imaging sensors increasingly used for navigation that are not yet integrated with the traditional GPS/IMU-based navigation filter. As a result of these developments, research has been very active in multisensory integration with specific attention directed towards using inexpensive MEMS sensors. To support this research, and combine broader international research efforts into ubiquitous positioning systems, a collaborative working group has been established under the banner of two international professional organizations: the International Association of Geodesy (IAG WG4.2.5) and the International Federation of Surveyors (FIG WG5.5). One of the aims of this WG is to support the broader research community through the provision of reference data sets to support algorithmic design, performance testing and various cross-performance validations. In cooperation with research teams from three international universities, a major test campaign was performed at the Ohio State University that included 12 IMU sensors. Navigation grade sensors provided the highest accuracy reference solutions and a tactical grade IMU was also used for cross-comparisons. The eight MEMS IMUs included the most frequently used models, and two identical sensors were also used to assess the performance fluctuations of a particular model type. Using a mobile platform, various data sets were acquired in different arrangements, including slow and fast dynamic motion, various acceleration/deceleration patterns in both linear and angular components. To support the broader applicability of the data, all the MEMS IMU data was preprocessed to a unified format, and using the high-end IMU in GPS/IMU integration, a reference solution was also provided. The specific objectives of field tests were:

- Acquire reference data for MEMS performance validation using high-end IMU’s
- Acquire reference data for algorithmic research (typical trajectories)
- Validate time synchronization performance of different implementations (embedded GPS, timer-board based and software-only PC data acquisition systems)
- Acquire data in various sensor configurations in highly dynamic environment
- Acquire data in a group of sensor nodes equipped with GPS/IMU of various grades

This paper briefly summarizes the implementation of these efforts to facilitate the use of the reference data set in the research community. The discussion includes sensor configuration, performance analysis of the reference data set, and an overview of the MEMS data and its accessibility to the IAG/FIG community.

2. SYSTEM CONFIGURATION

The field tests were carried out on the The Ohio State University (OSU) campus across the week of 12-16 May 2010. The mobile research platform was provided by OSU and various grades of IMUs, several GPS receivers and datalogging software were provided by all institutions including the University of Melbourne and the University of New South Wales, Australia. After two days of installation and testing, ten data acquisition surveys were conducted on 14-16 May, 2010. Table 1 lists the IMU sensors used in the field experiments, including interface and installation parameters.

IMU	Owner	Interface	Timing	Lever arm with respect to rear GPS antenna		
				Right [cm]	Front [cm]	Up [cm]
H764G-1	OSU	1553B	Built-in GPS	26.6	-76.1	123.6
H764G-2	OSU	1553B	Built-in GPS	48.2	-76.1	123.6
LN100	OSU	1553B	External(hw)	26.6	-71.7	102.8
HG1700	OSU	H/SDLC	External(hw)	48.5	-53.4	101.8
XBOW-0	OSU	Serial	External(hw)	53.5	-78.1	107.2
XBOW-1	UoM	Serial	External(sw)	43.8	-78.1	107.2
XBOW-2	UoM	Serial	External(sw)	30.4	-60.2	107.2
XSENS-1	UoM	USB	External(hw)	43.4	-71.4	109.8
XSENS-2	UNSW	USB	External(sw)	37.6	-71.4	109.8
Gladiator Landmark	UoM	Serial	External(sw)	53.9	-64.6	109.7
MicroStrain, INERTIA LINK	UoM	USB	External(sw)	47.6	-64.4	108.9
Crista IMU	UoM	Serial	External(sw)	37.9	-59.5	109.9

Table 1. IMU sensors used in the experiments, with GPS antenna lever arm data.

The IMU sensors were installed in a two-level rigid metal cage, where the lower plate held two Honeywell H764G navigation-grade IMUs, and all the other IMUs (10) were mounted on the upper plate; Fig. 1 shows the upper plate during sensor installation.

The IMU sensor installation mostly followed the ideal orientation with respect to the vehicle body frame, except when mechanical constraints prevented it. Table 2 shows the IMU coordinate correspondence to the vehicle body.

Vehicle axes	LN100	H764G	HG1700	XBOW	XSENS	Gladiator	MStrain	Crista
Right	Y	Y	Y	Y	-Y	Y	Y	Y
Front	X	X	Z	X	X	X	X	X
Up	-Z	-Z	X	-Z	Z	-Z	-Z	-Z

Table 2. IMU sensor orientation in the GPSVan.

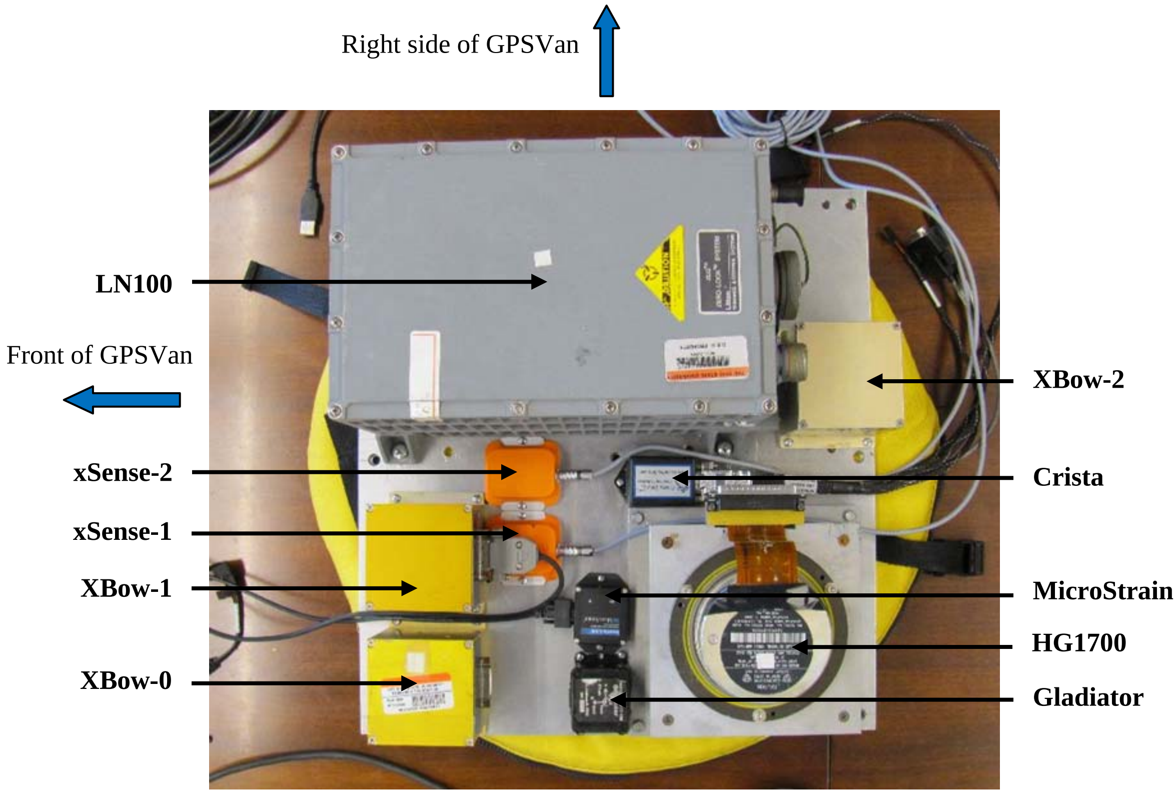


Figure 1: IMU sensors installed on the upper plate of the IMU cage.

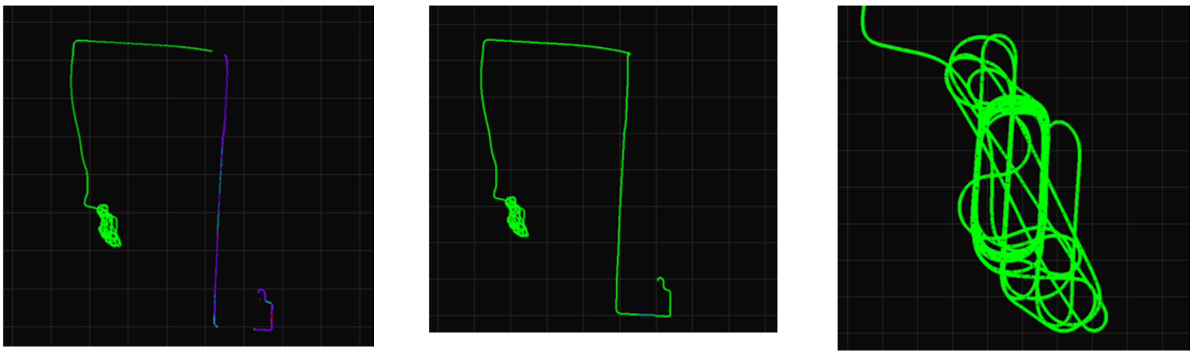
The five OSU IMU sensors are permanently installed in the GPSVan, so their locations were known from past highly accurate surveys, and the seven MEMS IMUs were relatively positioned to them; the lever arm parameters are listed in Table 1. The GPSVan is equipped with two GPS antennae, installed in the central vehicle direction and separated by 192 cm, see Fig. 2. The rear antenna served as the main antenna, so the lever arms are referenced to it. Since most of the MEMS IMUs are still manufactured without integrated GPS, additional circuits and software were needed to provide GPS time-tags to the MEMS IMU measurements. The front antenna primarily was used to support GPS time-tagging. Two 4-way splitters provided GPS antenna signals to the three GPS receivers in the GPSVan and for all IMU sensors with built-in GPS. Most of the GPS time-tagging solutions, used in our testing, were software-based, see Table 1; more details about GPS time-tagging can be found in (Toth et al., 2008).

3. FIELD EXPERIMENTS

The GPSVan, shown in Fig. 2, was used as a mobile platform to acquire data in various motion patterns, including straight and circular vehicle trajectories at various velocities and accelerations.

Figure 3: GPSVan in field tests at OSU Campus; note a GPS reference station in the back.

During the ten sessions, trajectories ranging from straight segments to repeated loops were driven on roads and in parking lots. Fig. 4 shows the trajectory of session 8; (a) is the differential GPS solution, (b) is the GPS/IMU integration solution, based on the H764G-1 IMU data, and (c) enlarges the maneuvering part in the parking lot. Note that two GPS gaps (6 and 11 seconds, marked in colors different from green) found in (a) are well bridged, as seen in (b). Obviously, there are no GPS gaps in the parking area, where most of the maneuvers were carried out. Fig. 4c shows that straight segments were acquired in the North-South, East-West and diagonal directions with various acceleration and decelerations along the straight parts. The loops were also driven in both directions and included "8"patterns too.



(a) (b) (c)

Figure 4: Trajectory of session 8; (a) DGPS solution, (b) GPS/IMU solution, and (c) maneuvering area.

4. REFERENCE SOLUTION AND MEMS DATA

The post-processed reference solution was computed using a Novatel OEM4 rover and a Topcon Legacy GPS base station, in the parking lot, and IMU data from the H764G-1 sensor. The loose-integration based GPS/IMU solution shows excellent performance, as expected since the trajectory falls in a mostly open-sky area. The Kalman-filter estimated standard deviation of position, velocity and attitude are shown in Figs. 5, 6 and 7, respectively.

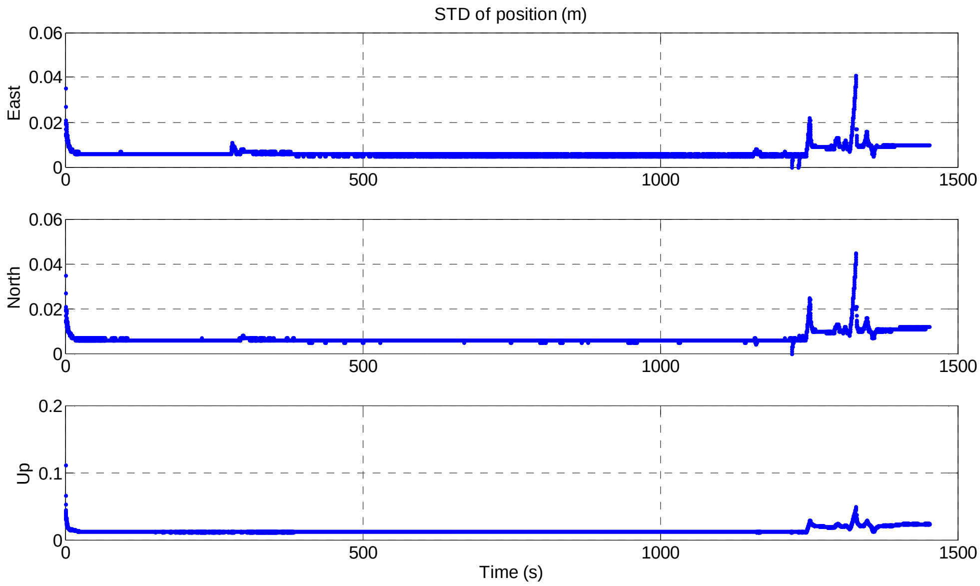


Figure 5: The standard deviation of position for session 8.

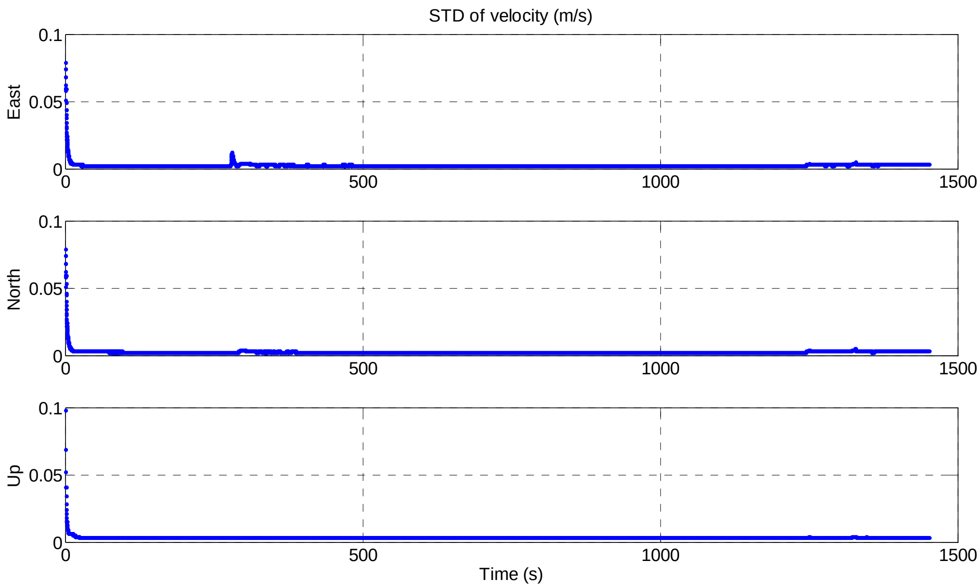


Figure 6: The standard deviation of velocity for session 8.

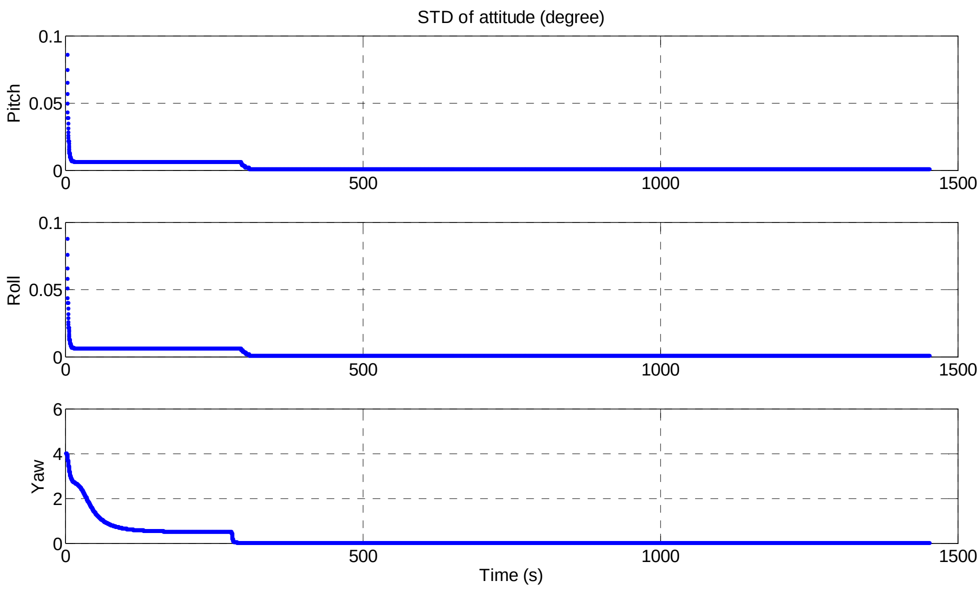


Figure 7: The standard deviation of attitude for session 8.

Session 8 started in the parking lot, and after finishing the various maneuvers, the GPSVan drove back to the staging area via public roads in the OSU West Campus. Fig. 8 shows the velocity solution. The velocity profile correlates well with the driving pattern, the loops in the parking lot, and road segments where GPS signal was lost or degraded due to tree foliage; compare it to Fig. 4a and the larger values in Fig. 5.

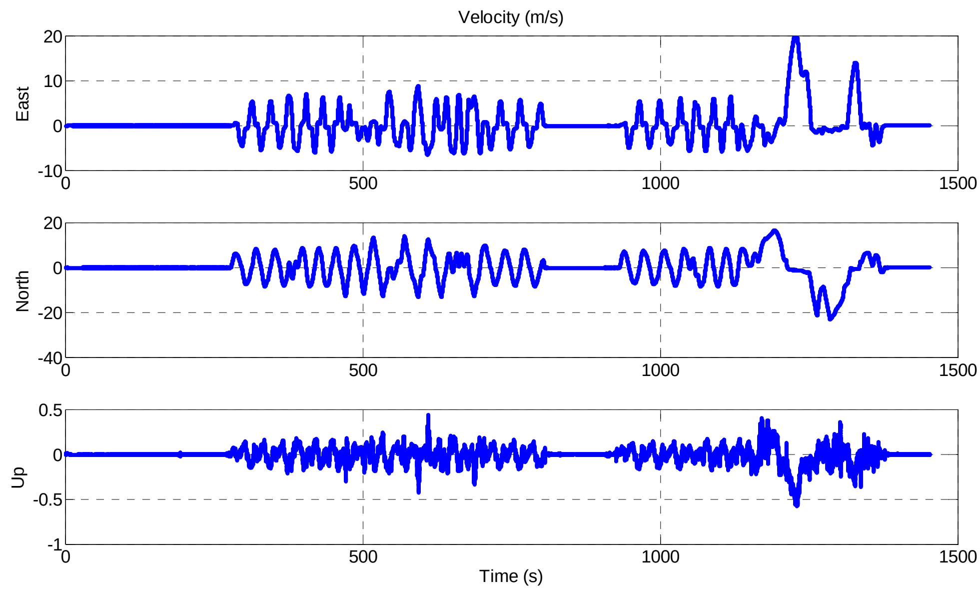


Figure 8: The velocity of east, north and up directions for session 8.

All the MEMS IMU data were pre-processed to assign GPS time-tags; during recording either the local high-resolution counter of CPU was used or the GPS time-tags were real-time estimated. The overall processing of MEMS IMU data have been done by six universities:

- SPIN Lab at The Ohio State University
- University of Melbourne, Australia
- University of New South Wales, Sydney, Australia
- National Technical University of Athens, Greece
- Budapest University of Technology and Economics, Hungary
- Vienna University of Technology, Austria

There are several publications in various preparation phases on reporting about MEMS IMU performance. The FIG web-portal, from where any interested researcher can access the entire data set, is maintained by University of Melbourne, Australia.

5. CONCLUSIONS

The FIG Working Group that was formed in 2009 to support research in using MEMS IMUs conducted a successful data acquisition campaign at the Campus of The Ohio State University in May 2010. Eight MEMS and four navigation/tactical-grade IMU sensors were used in a variety of kinematic testing. All the measurements were GPS time-tagged and a reference navigation solution was obtained based on using a navigation-grade IMU data in the GPS/IMU integration. The data, including the reference solution, MEMS measurements data, metadata and additional processing tools are available from the FIG WG portal, maintained by the University of Melbourne, Australia. There have been results published on MEMS performance on this demo data set and more are expected in the future.

REFERENCES

FIG WG5.5 http://www.fig.net/commission5/wgroups/wg5_5.htm

Fragos, K., Gikas, V., Kealy, A. (2010). Dynamic Modeling for Land Mobile Navigation Using Low-Cost Inertial Sensors and Least Squares Support Vector Machine Learning. 23rd International Technical Meeting of the Satellite Division of The Institute of Navigation, USA.

Grejner-Brzezinska, D.A., C. Toth and Sh. Moafipoor, (2008): A Step Ahead: Human Motion, Machine Learning Combine for Personal Navigation, *GPSWorld*, Vol. 19, No. 11, pp. 34-41.

IAG WG4.2.5, http://enterprise.lr.tudelft.nl/iag/iag_sc42.htm

Kealy, A., Roberts, G., Retscher, G. (2010). Evaluating the performance of low cost MEMS inertial sensors for seamless indoor/outdoor navigation. Proceedings PLANS 2010: IEEE/ION Position Location and Navigation Symposium.

Toth, C.K., Grejner-Brzezinska, D. A., Shin, S-W., Kwon, J. (2008). A Method for Accurate Time Synchronization of Mobile Mapping Systems, *Journal of Applied Geodesy*, Vol. 2, pp. 159-166.

BIOGRAPHICAL NOTES

Charles K. Toth is a Senior Research Scientist at the Ohio State University Center for Mapping. He received an M.S. in Electrical Engineering and a Ph.D. in Electrical Engineering and Geo-Information Sciences from the Technical University of Budapest, Hungary. His research expertise covers broad areas of 2D/3D signal processing, spatial information systems, high-resolution imaging, surface extraction, modeling, integrating and calibrating of multi-sensor systems, multi-sensor geospatial data acquisition systems, and mobile mapping technology. He is Chairing ISPRS WG I/2 on LiDAR and InSAR Systems and serves as the Director for the Photogrammetric Application Division of ASPRS.

Dorota A. Grejner-Brzezinska is a Professor in Geodetic Science, and director of the Satellite Positioning and Inertial Navigation (SPIN) Laboratory at The Ohio State University. Her research interests cover GPS/GNSS algorithms, in particular, high precision positioning and navigation, such as DGPS and RTK, GPS/inertial and other sensor integration for navigation in challenged environments, sensors and algorithms for indoor and personal navigation, Kalman filter and non-linear filtering. She published over 180 peer reviewed journal and proceedings papers, numerous technical reports and five book chapters on GPS and navigation, and led over 20 sponsored research projects. She is ION Fellow, and the recipient of the 2005 ION Thomas Thurlow Award, the 2005 United States Geospatial Information Foundation (USGIF) Academic Research Award, and ESRI Award for Best Scientific Paper in Geographic Information Systems published in 2004.

Nonie Polit is a graduate of the school of Electrical Engineering & Telecommunications at the University of New South Wales, Australia. He obtained a Bachelor degree in Telecommunication Engineering and a Masters of Engineering Science in Electronics. He is currently working as a research assistant at the School of Surveying and Spatial Information Systems, UNSW.

Allison Kealy is a senior lecturer in The Department of Infrastructure Engineerig at The University of Melbourne Australia. She holds an undergraduate degree in Land Surveying from The University of the West Indies, Trinidad, and a PhD in GPS and Geodesy from the University of Newcastle upon Tyne, UK. Allison's research interests include sensor fusion, Kalman filtering, high precision satellite positioning, GNSS quality control, wireless sensor networks and location based services. Allison is currently the co-chair of FIG Working Group 5.5 entitled Ubiquitous Positioning which is coordinated collaboratively with IAG Working Group 4.2.5.

CONTACTS

Charles Toth and Dorota Brzezinska
Department of Civil and Environmental Engineering and Geodetic Science
The Ohio State University
2070 Neil Avenue, Columbus, OH 43210-1275, USA
Tel: +1 614.292.7681 Fax: +1 614.292.2957
E-mail: toth@cfm.ohio-state.edu, dbrzezinska@osu.edu

Nonie Politi
School of Surveying and Spatial Information Systems
University of New South Wales
Sydney, NSW 2052 Australia
Tel: +61 2 9385 4020
E-mail: nonie@unsw.edu.au

Allison Kealy
Melbourne School of Engineering
The University of Melbourne
Victoria 3010 Australia, Australia
Tel: +61 3 8344 6804 Fax: +61 3 8344 4616
E-mail: a.kealy@unimelb.edu.au