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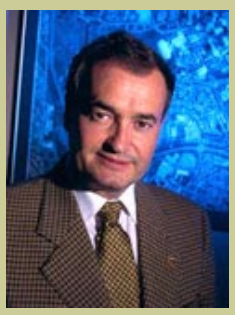
CHAIRHOLDER PROFILES



Gérard Lachapelle
Canada Research Chair in Wireless Location
The University of Calgary
Tier 1 - April 1, 2001

Achievements: Johannes Kepler Award – The U.S. Institute of Navigation's highest honour, reserved for exceptional achievement

Research Involves: Establishing a new research group to develop super-accurate wireless location systems

Research Relevance: Provides new navigation tools and emergency services to cellular telephone users and the transportation industry

LOCATION IS EVERYTHING

Location. Location. Location. They're the three most important words in real estate – and now in wireless communication.

The cellular phone of the future will be expected to go beyond providing communication and Internet service. It will have to serve as a location beacon for the user. Developing super-accurate location technology is the objective of the newly created Wireless Location Research Group (WLRG) at the University of Calgary.

It's estimated that by 2003, there will be 800 million cellular phones in use worldwide. Concerns for public safety have resulted in a U.S. regulation requiring emergency 911 services for mobile telephone customers. The regulation calls for an accuracy of 100 metres, but that will be inadequate for those living in high-rises or working in office towers. These future services will require far more accurate location methods than are currently available.
Other demands for wireless location services include, precision control of agricultural planting equipment, structure monitoring and the need for 3-D marine navigation in constricted waterways. And trucking firms are demanding more accurate ways to keep track of their fleets.

The Global Positioning Satellite (GPS) system cannot adequately meet the needs of these future location-based services. (Signals from the satellite-based system frequently cannot easily penetrate treetops and buildings, and are only accurate to within 20 metres.) New super-accurate systems will soon be under development and testing thanks to funding provided by the Canada Research Chair in Wireless Communication.

The recipient of the Chair, Gérard Lachapelle is an internationally respected and awarded authority in the navigation community. During a career that has spanned 30 years, he has continually improved navigational methods and inspired students working with him to develop their own breakthroughs. Under his direction, the WLRG will embrace a multidisciplinary approach to discovering new wireless location systems.

The group will be looking at ways to enhance existing systems by augmenting them in a number of ways. GPS systems may one day be augmented by other satellite-based systems and by ground-based transmitters in high-density areas. The signals they transmit often bounce off buildings and other structures causing errors.

The research program is expected to attract great interest and support from the telecommunications industry. Surveys indicate that 70 percent of current Internet users want to go mobile and will demand services requiring the accurate wireless location technology.

DR GÉRARD LACHAPELLE

WIRELESS LOCATION RESEARCH GROUP (WLRG)

iCORE Chair
Geomatics Engineering
University of Calgary

Dr Gérard Lachapelle holds an iCORE Research Grant in Wireless Location at the University of Calgary. iCORE has committed $500,000 per year for five years for a total of $2.5 million dollars to develop this research group.

EXECUTIVE SUMMARY

This iCORE grant, which began in January 2001, focuses on research related to outdoor and indoor wireless location, high performance navigation and positioning using satellite and ground-based radio frequency (RF) techniques, and fusion with self-contained sensors for personal navigation. The major performance parameters that are the focus of the research are availability, accuracy and reliability.

Strong collaboration with four faculty members at the University of Calgary and one at the University of Alberta, in addition to a wide range of external partnerships and sponsorships from outside organizations contributed much to the progress that was achieved on 10 major research projects ranging from indoor location using satellites to high precision positioning using satellite signals integrated with self-contained sensors and the development of a software Global Navigation Satellite System receiver. These research projects resulted in personnel training, publications and intellectual property transfer. Personnel training consisted in the completion of one MEng and four PhD students directly supervised or co-supervised by the chair, the hiring of four senior research associates and the supervision and co-supervision of 21 MSc and PhD candidates, including 10 that began during the reporting period. Eleven papers were published and five were accepted for publication in refereed journals, and 15 were presented at conferences. The chairholder made numerous invited oral presentations in Canada and abroad. Intellectual property transfer consisted of licensing of software and in technology transfer through external contracts and grants valued at $350,000. New partnerships were established with Aeronautical Radio Inc. (ARINC), US, Tampere University of Technology, Finland, and the University of Carleton. In recognition of their efforts, numerous members of the team and collaborators received awards.

Thanks to the success of the chairholder and his collaborators in securing external sponsors for the above research activities, another $1.6 million was raised in funding, in addition to the iCORE grant of $0.5 million. The objective to use the iCORE grant to leverage additional funds was exceeded.

Challenges in the first year of the grant included the search for specialized and high quality senior research personnel and the management of the team spread over five different areas during the start-up phase. The chairholder's group now occupies contiguous space in the Calgary Centre for Innovative Technology (CCIT) where they have had access to a modern navigation laboratory and antenna range since October 2002.

RESEARCH GOALS AND OBJECTIVES

The specific research objectives for this reporting period were as follows:

- study the propagation properties of radio frequency (RF) waves at 1.5 GHz through various materials for outdoor-to-indoor ranging purposes;
- study the feasibility of integrating self-contained MEMS sensors with RF techniques for personal location and navigation in urban canyons and indoors;
- continue the development of the multiple reference station technique MultiRef™ for GPS real-time kinematic positioning and proceed with the deployment of a 16-station test and demonstration network in southern Alberta;
- continue investigations of ground-based cellular telephone CDMA location techniques;
- continue performance analyses of Galileo and combined GPS/Galileo systems, now that the European Union has made a firm decision to proceed with the deployment of that system;
- continue investigations related to the use of high sensitivity GPS receivers under outdoor and indoor signal masking conditions and design new applications;
- continue investigations related to various aspects of GPS, including receiver performance testing, development of reliability methods for GPS-based attitude determination and RTK methods;
- seek and exploit new opportunities related to location, positioning and navigation as they arise, e.g., participation in the U.S. DoD Joint Precision Approach and Landing Project (JPALS).

These objectives were achieved partly as a result of effective collaborations with other faculty members in the department of geomatics engineering at the University of Calgary and outside collaborators and partners, and partly as a result of substantial additional external financing.

RESEARCH PROJECTS

The following 10 major projects were the focus of the chair-holder's team during the reporting period:

a) RF Propagation

The effects of building materials on UHF ranging signals were investigated to assess signal behavior as a function of materials, carrier modulation technique and signal strength. Signal behavior analysis included carrier and amplitude attenuation, related increased measurement noise, signal reflection and refraction, and effect of Fresnel zones. This fundamental research is necessary in order to understand the full potential and limitations of RF indoor location.

This work was done in collaboration with Professors Cannon and Klukas, in the department of geomatics engineering. The project, supported by the Department of National Defence (DND), is part of a larger DND effort to assess the feasibility of performing high accuracy (2 m) personal positioning and guidance indoor using an integrated system. A technical report was submitted to DND and a paper submitted to a refereed journal.

b) Indoor GPS location

This research activity is central to the activities of the research group. Investigations into the performance of high sensitivity equipment were continued. High sensitivity equipment uses longer signal integration time to increase the signal to noise ratio.The investigations were divided into two tasks, namely in-situ testing and hardware simulations. The in-situ testing consisted of performing static and kinematic measurements in selected environments to assess signal fade and noise, carrier phase, range and Doppler measurement quality, and related location availability and accuracy. Field testing under a wide range of forest environments was conducted outside Calgary, in Victoria, British Columbia, and

Montréal, Québec, partly shaded signal testing was conducted in downtown Calgary and on the University of Calgary campus, and indoor testing was conducted inside light residential and agricultural buildings in the Calgary area. These measurements were used to characterize the GPS signal channel and its stochastic properties under the environ-ments tested. The second task consisted in investigating the possibility of reproducing, in a stochastic sense, the above field environments using a newly available hardware simulator. The latter, developed by Spirent Communications, U.K., in the early 2002 partly using GPS signal propagation channel characteristics developed in 2001 by the chairholder's research group, allows for a variety of signal characteristics to be modeled. Early results obtained in late 2002 and early 2003 indicate that such a method is indeed feasible. This result is very important, as it will allow high sensitivity GPS receiver manufacturers and cellular telephone service providers to conduct performance analysis and compliance testing under known and controlled conditions. Such compliance testing is required by the U.S. FCC and will likely be required by other regulatory agencies. GPS receiver deployment in cellular telephones is occurring at an estimated rate of 2M units per month in 2003.

This work was conducted in cooperation with Professors Cannon and Klukas, department of geomatics engineering at the University of Calgary, Spirent Communications, U.K., and with the assistance of SiRF Technology Inc., CA. A paper presented by the University of Calgary/Spirent team at the GPS 2002 international conference received an award.

c) Outdoor/indoor vehicular and personal location and navigation using GPS integrated with self-contained sensors

This activity focused on investigating self-contained MEMS sensor performance for vehicular and personal location and navigation and in designing novel methods and algorithms to integrate these together and with GPS. Investigations into the integration of high sensitivity GPS with a low cost rate gyro for vehicular navigation resulted in a 50 percent increase in availability in urban canyons. This system is, in turn, being used to develop an advanced traveller information system while ultimately increasing the road network capacity. Analysis into the performance and combination of various miniature low cost sensors for personal use resulted in numerous promising findings. For instance, a system consisting of an array of accelerometers and magneto-resistive sensors mounted on the user's footware was designed and tested to improve the relative location of the user moving outdoor or indoor. Thermal effects on accelerometers and gyros were investigated. Design work on the integration of GPS with these sensor types was initiated. A portable test multi-purpose system that includes a high performance integrated inertial navigation system/GPS to provide reference trajectories was designed. Limited testing in the field under various environments was conducted.

This work was conducted in cooperation with Professor El-Sheimy, department of geomatics engineering at the University of Calgary, Professor K. Fyfe, department of mechanical engineering at the University of Alberta, and with some financial support from the industry, the Auto 21 National Centre of Excellence and the Department of National Defence.

d) High performance GPS and GPS/INS integration

Methods to improve differential carrier phase GPS navigation and guidance accuracy and reliability performance were investigated, with emphasis on augmentation with a tactical grade inertial system. Statistical reliability theory was used to derive reliability measures for the integrated GPS/INS system. The methods and algorithms that resulted from this research were embedded in software package SAINT™ (Satellite And Inertial Navigation Technology).

This work was conducted in cooperation with Professor Cannon, department of geomatics engineering at the University of Calgary. Financial assistance was received from the US Navy through a contract with Aeronautical Radio Inc. (ARINC) to test algorithms and methods during the latter part of the project.

e) Assessment of GPS/Galileo performance

Research into the accuracy, availability and reliability performance of the forthcoming European Union's Galileo system versus those of GPS and combined GPS/Galileo focused on the use of multiple-frequency

range and carrier phase observables. A method to simulate GPS and Galileo measurements in software with controlled error levels was completed. This methodology and algorithms developed were embedded into two software packages, namely SIMGNSS1™ and the SIMGNSS2™. The above simu-lated measurements were then used in other software developed by the research team to comparatively assess performance. This work will be useful to the research team in the years ahead to upgrade its GPS software to Galileo and GPS/ Galileo.

This work was conducted in cooperation with Professor Cannon, department of geomatics engineering at the University of Calgary. Financial assistance was received from the Canadian Space Agency as the work formed part of Canada's contribution to the overall Galileo effort.

f) High precision multiple reference station GPS real-time kinematic positioning and GPS meteorology

Research on the use of a GPS reference network to improve real-time kinematic carrier phase positioning for users located in the network coverage area was pursued. Enhanced algorithms were embedded in MultiRef ™, a software package developed during the past four years by the research team. A small scale, four-station test network deployed north of the University of Calgary was used to test the algorithms and software in real-time. Deployment of a medium scale (200 km x 200 km), 16-station network in Southern Alberta was initiated. The method was also tested on a 12-station GPS network located in the Campania region of Italy. Smoothing algorithms for a post-mission version of MultiRef™, namely MultiRefPM™, were also developed and tested. The post-mission version of this method is expected to be of interest to numerous private sector organizations. Investigations into using the above medium scale network to estimate atmospheric water vapour variations in real-time were initiated. This effort is expected to contribute to meteorological research in the long term.

The above research was conducted in cooperation with Professors Cannon and Skone, department of geomatics engineering at the University of Calgary, the Universita' Degli Studi di Napoli Parthenope, Italy, and with the assistance of the Applanix Corporation, Toronto, and NovAtel, Calgary.

g) Wireless location using ground based systems

Investigations into the use of cellular telephone networks to provide outdoor and indoor location were continued in cooperation with Dr Klukas, geomatics engineering, and focused on a IS-95 pilot signal hearability analysis, and non line-of-sight error mitigations for the time difference of arrival (TDOA) and angle of arrival (AOA) methods. Parameters such as the cellular channel propagation model and detection threshold were taken into account. Integration of these ground-based methods with differential barometry to deal with cell/user height differences and with GPS pseudorange measurements was also researched.

h) Initial development of a GNSS software receiver

Initial research was started into the development of a GNSS software receiver capable of operating with the current GPS and the forthcoming Galileo system, GPS II and III. The fundamental design of the receiver was laid out and sub-divided into tasks that can be undertaken by different researchers. This project, which also includes the development of a software transmitter, is expected to last three years and will require some 15 person-years to complete. Components to become available throughout the next three years will be usable for a variety of research projects. The advantage of a GNSS software receiver will be the ability to develop and assess the behavior of advanced signal processing techniques to improve performance. This is the more important given that actual Galileo and GPS II and III signals will not be available for several years. This project is being conducted cooperation with Professor Cannon and is funded by the chair holder's iCORE grant and NSERC discovery grants at this time. However additional funding sources are being investigated.

i) Integration of a multiple GPS receiver system and self contained sensors for attitude determination

Such a system is used not only to determine position but also to determine the attitude parameters (roll, pitch and yaw) of the mobile or stationary platform on which the integrated system is rigidly mounted. Low cost GPS receivers, antennas and rate gyros were

integrated in software using an innovate series of algorithms to optimize availability and reliability. The effect of antenna phase centre instabilities and GPS data gaps were quantified, together with the advantages of the rate gyros.

j) Ship multipath and receiver reliability

GPS receiver reliability is of great concern to marine organizations when GPS is used for precise applications such as shipping in constricted waterways and buoy tendering. A significant error source is multipath, caused by signal reflection from the ship infrastructure and surrounding water. Receiver response to this effect and other errors is a function of the receiver internal firmware. Ship multipath occurrence was measured during a four-day observation campaign on a ship and receiver response was analysed using a GPS simulator. This research was conducted with the support of the Canadian Coast Guard.

RESEARCH TEAM

TEAM LEADER	AWARDS
Gérard Lachapelle	Fellow, Royal Society of Canada Canada Research Chair, Wireless Location Honorary Professorship, University of Wuhan, China
TEAM MEMBER/COLLABORATOR	**TITLE**
Richard Klukas	Assistant Professor
Elizabeth Cannon	Professor, NSERC Steacie Fellowship 2002-2004
Susan Skone	Assistant Professor, NSERC UFA, 1999-2004
Naser El-Sheimy	Associate Professor
OTHER TEAM MEMBERS	**RESEARCH TOPIC**
Ken Fyfe, U of A	Self-contained Pedestrian Navigation Systems
Jong-Uk Park, Korea Astronomical Observatory	GNSS High Precision Navigation
Bruno Scherzinger	Applanix Corporation, Adjunct Professor
Mark Petovello	GNSS and Integrated GNSS/INS
Aaron Morton	RF Propagation, Interference, and Digital Signal Processing
Glenn MacGougan	System Testing, Indoor Location, Navigation Laboratory

POSTDOCTORAL FELLOWS	TOPIC
U. Dogan	Visiting NATO scholar, until August 2002

PHD CANDIDATES	TOPIC	AWARDS
Samuel Ryan	Augmentation of GPS for Reliable Marine Navigation	Killam
Edvaldo Fonseca (external - Brazil)	Ionospheric Effects on GPS Transmission	
Giovanni Pugliano (external - Italy)	Multiple Reference Station GNSS RTK	
Kyle O'Keefe	Design of a Satellite-based Navigation System for Mars	PGS-B, iCORE Graduate Student Scholarship
Paul Alves	High Performance Multiple Reference Station GNSS RTK	PGS-B
Changlin Ma	Advanced Ground-based Techniques to Improve Wireless Location	
Chaminda Basnayke	GPS-based Transit Probe System	
Bo Zheng	GNSS Multipath Modeling and Software Receiver	
Oleg Mezentsev	GPS and Inertial Navigation Systems for Personal Outdoor/indoor Navigation	
Olivier Julien	Software GNSS receiver development	
Jussi Collin (external-Finland)	GPS and MEMS Sensors for Personal Outdoor/indoor Navigation	

Walid Abdel-Hamid	MEMS-based INS/GPS for Vehicular Positioning and Navigation	
Mohammad Rajabi	Digital Terrain Model Derivation from Satellite Imagery	
Roger Edwards (external - Univ. of Carleton)	GPS Interference	
Yong Ahn	High Performance Multiple Reference Station GNSS RTK	

MSC CANDIDATES	TOPIC	AWARDS
Yan Lu	Electrical Engineering	
Glenn MacGougan	Indoor Location with GPS	PGS-A, iCORE Graduate Student Scholarship
Chaochao Wang	Attitude Determination with Multiple-antenna GPS Systems	
Lei Dong	GNSS RF Software Transmitter	
R. Stirling	Personal Outdoor/indoor Navigation using MEMS Sensors	PGS-A
Joseph Angelo	GNSS Interference	
Rob Watson	Indoor Location	
Dhar Karunanayake	GNSS	
Diep Dao	Integration of GPS and MEMS Sensors for Personal Outdoor/indoor Navigation	
Zhi Jiang	GNSS Software Receiver Development	
Ping Lian	Indoor Location	

UNDERGRADUATES	TOPIC
Kees Lap Siu	Internship Student
Doug Langen	Internship Student
Lance De Groot	Internship Student

COLLABORATIONS

Active collaboration in the form of joint research projects and/or funded research projects took place with a variety of organizations. These include:

INSTITUTION	RESEARCHERS	NATURE OF COLLABORATION
Department of Geomatics Eng, Univ. of Calgary	R. Klukas, M. E. Cannon, N. El-Sheimy and S. Skone	GNSS and MEMS sensors
Department of Mechanical Eng, Univ. of Alberta	K. Fyfe, R. Stirling	Personal location using self-contained sensors
Department of Civil Eng, Univ. of Calgary	A. MacIver	Collaboration on use of GPS for vehicular traffic modeling
Department of Electronics, Carleton University	R. Edwards, J. Wight	GPS interference analysis
Dept of Electrical and Informatics Eng, University of Sherbrooke	J. de Lafontaine, F. Michaud	NCE Auto 21 collaborative vehicular driving systems and integrated systems
Universita' Degli Studi di Napoli Parthenope, Italy	G. Pugliano	Multiple reference station GPS RTK positioning
Tampere University of Technology, Finland	J. Takala, J. Collin	Personal location and navigation
Dept of National Defence, Defence Research Development Canada	J. Bird, N. Brousseau, M. Vinnins	Financial support for Tactical Indoor Positioning System and groud-based IS-95 wireless location development

INSTITUTION	RESEARCHERS	NATURE OF COLLABORATION
Canadian Coast Guard	S. Ryan	Ship GPS multipath assessment and receiver reliability
Dominion Radio Astrophysical Observatory, Penticton B.C.	P. Dewdney	Precise positioning for large adaptive reflector to be used in radio astronomy
Nokia Mobile Telephone Company, Finland	S. Turunen, J. Syrjarinne	Wireless location of cellular telephones
SiRF Technology Inc, U.S.A.	G. Turetzky	Collaborative technical support, high sensitivity GPS receiver assessment
Spirent Communications, U.K.	P. Boulton, A. Read	Common research on indoor location simulation enhancements
Univ. of Sao Paulo Polytechnical School	D. Blitzkow, R. Bueno	Collaboration on the use of precise GPS for bridge motion monitoring
ARINC/U.S. Navy, U.S.A.	F. Allen, M. Lage	Financial support, Joint Precision Approach and Landing System
NovAtel, Calgary	P. Fenton. T. Murfin	Technical support - Internet/ Modem capable GPS receivers for Southern Alberta RTK Network, Galileo assessment
Applanix Corporation	B. Scherzinger	MultiRefPM(tm) development and testing
Canadian Space Agency	n/a	Financial support, GPS/ Galileo performance assessment

FUNDING

The amounts reported below have been pro-rated for the 12-month reporting period, even if the grant or contract is multi-year and has a total higher value.

The amount in external R&D grants and contracts raised by the grant holder as prime investigator was $1.2 million. In addition to iCORE funding of $500,000, Dr Lachapelle received $200,000 from his Tier 1 Canada Research Chair, $65,000 from his NSERC Discovery Grant, $60,000 from the telecom industry, $150,000 from his CFI ISRIP, and $40,000 from the National Centres of Excellence Auto 21 project. Revenue from the Canadian Coast Guard is $23,000, plus $12,000 from a CFI project at the University of Victoria, $60,000 from ARINC and the US Navy, $98,000 from the Department of National Defense, and $5,000 from ATS.

Research teams involving the grant holder raised another $0.6 million revenue as a co-investigator includes $43,000 (with Dr Cannon, from the Canadian Space Agency), NSERC Strategic Grants of $114,000 with Dr El-sheimy et al and $90,000 with Dr Cannon et al, $10,000 with Dr Cannon from NRCan, $300,000 with Dr Cannon et al from the CFI/CCIT equipment grant, $32,000 from Shell Canada with Dr Tait et al, and $7,000 with Dr. Cannon et al from other industrial sources.

INTELLECTUAL PROPERTY

During Reporting Period

Some of the processes and algorithms developed during the reporting period and, in some cases, initiated previously, were embedded in software that were disclosed to University Technologies International (UTI). These new software packages consist of SAINT™ (Satellite And Inertial Navigation Technology), NDL™ (Navigation Development Laboratory), SimGNSS1™ (Software Simulator for Global Navigation Satellite Systems One), and SimGNSS2™ (Software Simulator for Global Navigation Satellite Systems 2). In addition, the following software packages, developed previously, were maintained and enhanced: C3NAVG2™, FLYKIN+™, HEADRT+™ and MULTIREF™. The revenue generated by UTI during the reporting period was $75,000, down from $550,000 for the previous reporting period, due to a slowdown in the IT industry. The outlook for the next 12-month however looks better.

In addition to the above, somae of the intellectual property developed by the grantholder was transferred to third parties (industry and Canadian and foreign government agencies through grants and contracts. The value of this activity during the reporting period was in excess of $300,000.

The total value of the IP transfer during the reporting period was therefore $375,000.

Potential for Future Commercial Activity

The chair holder and his colleagues continue to seek commercial opportunities for their existing and forthcoming intellectual property on an on-going basis, in the form of industrial research grants and contracts, licenses, and equity position in new commercial ventures. They will built on their past success and expertise to achieve this objective. UTI will continue to serve as the university licensing arm for these activities. Given the chairholder's extensive contacts with a broad range of organizations interested in his team's work, this type of commercial activity is expected to grow substantially during the next three years.

PUBLICATIONS

Refereed Journals

1. M.E. Cannon, G. Lachapelle, G. MacGougan, R. Klukas, P. Boulton, and A. Read, "Weak Signal Environment Testing of a High Sensitivity GPS Receiver in the Laboratory," *GPS World*, vol. 14, no. 3 (March), 2003, pp. 24-32.
2. C. Wang, and G. Lachapelle, "GPS Attitude Determination Reliability Performance Improvement Using Low Cost Receivers," *Journal of Global Positioning Systems*, vol. 1, no. 2, 2002, pp. 85-95.
3. G. MacGougan, G. Lachapelle, R. Klukas, K. Siu, L. Garin, J. Shewfelt, and G. Cox, "Performance Analysis of A Stand-Alone High Sensitivity Receiver," *GPS Solutions*, Springer Verlag, vol. 6, no. 3, 2002, pp. 179-195.
4. M. Olynik, M.G. Petovello, M.E. Cannon, and G. Lachapelle, "Temporal Impact of Selected GPS Errors on Relative Point Positioning," *GPS Solutions*, vol. 6, no. 1-2, 2002, pp. 47-57.
5. G. Lachapelle and G. Pugliano, "Posizionamento GPS Network RTK: il metodo MultiRefä," *Bollettino della SIFET*, N° 3, 2002, pp. 5-15.
6. G. Lachapelle, M.E. Cannon, K. O'Keefe and P. Alves, "How will Galileo Improve Positioning Performance?" *GPS World*, vol. 13, no. 9 (September Issue), 2002, pp. 38-48.
7. K. O'Keefe, S. Ryan, and G. Lachapelle, "Global Availability and Reliability Assessment of the GPS and Galileo Global Navigation Satellite Systems," *Canadian Aeronautics and Space Journal*, Canadian Aeronautics and Space Institute, vol. 48, no. 2, 2002, pp. 123-132.
8. S. Ryan and G. Lachapelle, "Augmentation of DGNSS With Dynamic Constraints For Marine Navigation," *Lighthouse*, Canadian Hydrographic Association, Ottawa, No. 61, 2002, pp. 17-25.
9. L.P. Fortes, M.E. Cannon, S. Skone, and G. Lachapelle, "Improving a Multi-Reference GPS Station Network Method for OTF Positioning in the St. Lawrence Seaway," *Lighthouse*, Canadian Hydrographic Association, No. 61, 2002, pp. 4-11.
10. G. Lachapelle and S. Ryan, "Future Trends in Marine Navigation and Positioning Technology," *Lighthouse*, Canadian Hydrographic Association, No. 60, 2002, pp. 15-22.
11. G. Lachapelle and P. Alves, "Multiple Reference Station Approach: Overview and Current Research," Invited Contribution, Expert Forum on VRS, *Journal of Global Positioning Systems*, vol. 1, no. 2, 2002, pp. 133-136.
12. Liu, J., M.E. Cannon, Pl. Alves, M.G. Petovello, G. Lachapelle, G. MacGougan and L. DeGroot (2003) A Performance Comparison of Single and Dual Frequency GPS Ambiguity Resolution Strategies. *GPS Solutions*, 7, 2, 87-100.

Accepted Publications by Refereed Journals

1. U. Dogan, G. Lachapelle, L. Fortes, and S. Ergintav, "A Study of the Tectonically Active Marmara Region, Turkey, Using GPS," *Can. Journal of Earth Sciences*, 2003, in press.
2. R. Klukas, G. Lachapelle, C. Ma, and G. Jee, "A GPS Signal Fading Model for Urban Centres," IEE *Proceedings of Microwaves, Antennas and Propagation*, 2003, in press.
3. N. Luo and G. Lachapelle, "Precise Relative Positioning of Multiple Platforms Using GPS Carrier Phase Ambiguity Constraints," *IEEE on Aerospace and Electronic Systems*, 2003, in press.
4. L. Fortes, L., M.E. Cannon, G. Lachapelle, and S. Skone, "Optimizing a Network-Based RTK Method for OTF Positioning," *GPS Solutions*, 2003, in press.
5. U. Dogan, P. Alves, G. Lachapelle, and S. Ergintav, "Testing a Multiple Reference Station GPS Network for Real-Time Carrier Phase-Based Positioning in the Marmara Region, Turkey," *Survey Review*, 2003, accepted for publication.

Conferences

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2. M. Petovello, M.E. Cannon, and G. Lachapelle, "Quantifying Improvements from the Integration of GPS and a Tactical Grade INS in High Accuracy Navigation Applications," Proceedings of NTM03, The Institute of Navigation, 2003, pp. 454-465.
3. G. Lachapelle, J. Clark, and R. Breslau, "Real Time Measurement of GPS Antenna Motion For JPALS," NATO RTO-SET Fall 2002 Symposium on Emerging Military Capabilities Enabled by Advances in Navigation Sensors, Istanbul, 14-16 October, 2002, CR-ROM.
4. G. Lachapelle, "Global Navigation Satellite Systems: Emerging Capabilities and Research Opportunities," Invited Paper, Veikko A. Heiskanen Symposium- A look to the future, Ohio State University, Columbus, OH, 2-4 October, 2002, Contribution 10.2, CD-ROM.
5. O. Mezentsev, Y. Lu, G. Lachapelle, and R. Klukas, "Vehicular Navigation in Urban Canyons Using a High Sensitivity Receiver Augmented with a Low Cost Sensor," Proceedings of GPS2002 (Session E1, Portland, OR, 24-27 September), The Institute of Navigation, 2002, pp. 363-369.
6. P. Boulton, A. Read, G. MacGougan, R. Klukas, M.E. Cannon, and G. Lachapelle, "Proposed Models and Methodologies for Verification Testing of AGPS-equipped Cellular Mobile Phones in the Laboratory," Proceedings of GPS2002, The Institute of Navigation, 2002, pp. 200-212. (Best Paper Presentation Award)
7. G. MacGougan, and J. Liu, "Fault Detection Methods and Testing," Proceedings of GPS2002, The Institute of Navigation, 2002, pp. 2668-2678. (Best Student Paper Award)
8. C. Wang and G. Lachapelle, "GPS Attitude Determination Reliability Performance Improvement Using Low Cost Receivers," Proceedings of GPS2002, The Institute of Navigation, 2002, pp. 1064-1074.
9. P. Alves, G. Lachapelle, M.E. Cannon, J. Park. And P. Park, "Use of Self-Contained Ionospheric Modelling to Enhance Long Baseline Multiple Reference Station RTK Positioning," Proceedings of GPS2002, The Institute of Navigation, Alexandria, VA, 2002, pp. 1388-1399.
10. J. Liu, P. Alves, M. Peetovello, G. MacGougan, L. de Groot, M.E. Cannon, and G. Lachapelle, "Development and Testing of an Optimal Cascading Scheme to Resolve Multi-Frequency Carrier Phase Ambiguities," Proceedings of GPS2002, The Institute of Navigation, Alexandria, VA, 2002, pp. 933-944.
11. M.E. Cannon, S. Skone, Y. Gao, Y. Moon, K. Chen, S. Crawford, and G. Lachapelle, "Performance Evaluation of Several Wide-Area GPS Services," Proceedings of GPS2002, The Institute of Navigation, 2002, pp. 1716-1726. (Best Paper Presentation Award)
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