Report on Kinematic and Integrated Positioning Systems

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Key words: GPS, Inertial Systems, Navigational Aid, Vision-Based Systems.

ABSTRACT

The paper presents the final report of the FIG C5 WG3 on Kinematic and Integrated Positioning Systems. It will cover both, the concept of integration and implementation aspects of integrated systems. Examples on current and future systems for mapping, positioning, and navigation applications will be given.

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1. INTRODUCTION: THE NEED FOR INTEGRATED SYSTEMS

The Global Positioning System (GPS) is capable of providing all ranges of positioning accuracy in all situations where uninterrupted signal reception is possible and the general satellite geometry is within acceptable limits. It is also evident that other navigation technologies, such as Inertial Navigation Systems (INS), are currently not capable of providing similar accuracies at a comparable price, i.e. there is no real competition to GPS in a scenario of uninterrupted signal reception. This leaves two scenarios to be considered. The first one is that of intermittent signal reception, as for instance in heavily forested areas or in urban centres. The other one is that of no signal reception at all, as for instance in buildings, underground or underwater. In the first case, GPS has to be integrated with other sensors to bridge periods of no signal reception. In the second case, GPS has to be replaced by another system that can provide continuous navigation in those environments where GPS does not work. Both cases will be treated in this paper where the integration of systems and navigational aids (navaids), will be investigated as an alternative for times of no GPS signal reception. In terms of systems, both INS and vision-based systems will be considered. In terms of navaids, odometers, gyros and digital maps will be considered for land vehicle navigation, and pedometers, magnetic compasses, digital maps, and cellular phones for backpack systems.

Integrated systems will, therefore, provide a system that has superior performance in comparison with either a GPS, an INS, or vision-based stand-alone system. For instance, GPS derived positions have approximately white noise characteristics over the whole frequency range. The GPS-derived positions and velocities are therefore excellent external measurements for updating the INS and providing the imaging sensors with position parameters, thus improving its long-term accuracy. Similarly, the INS can provide precise position and velocity data for GPS signal acquisition and reacquisition after outages and the orientation parameters for the vision-based system. The vision-based system can be used as a backup navigation system and to update the INS data if the GPS signal is blocked for long periods. In general, the fact that redundant measurements are available for the determination of the vehicle trajectory parameters greatly enhances the reliability of the system.

2. CURRENT INTEGRATED POSITIONING AND NAVIGATION MARKET

The current market of integrated positioning and navigation systems is clearly dominated by those systems that have GPS as one of their components. Besides being globally available, GPS provides the whole range of navigation accuracies at very low cost. It is also highly portable, has low power consumption, and is well suited for integration with other sensors, communication links, and databases. At this point in the development of navigation technology, the need for alternative positioning systems only arises because GPS does not work in all environments.

Figure (1) shows the projected development of GPS module cost. For the accuracy range considered here, it has reached the unit price of about $100 and predictions are that it will drop to about $50 by 2005 when, most likely, it will level off. Modules cost are not equivalent to system cost, but the recent development of navigation receivers at a price of a few hundred dollars shows clearly that module cost is an important factor. Even more important is the fact that with unit cost that low, GPS is becoming a commodity, comparable to a Sony Walkman, pocket calculators, or a digital wristwatch. Thus, personal GPS devices will soon start to drive the module market and provide navigation receivers of high versatility at even lower cost.

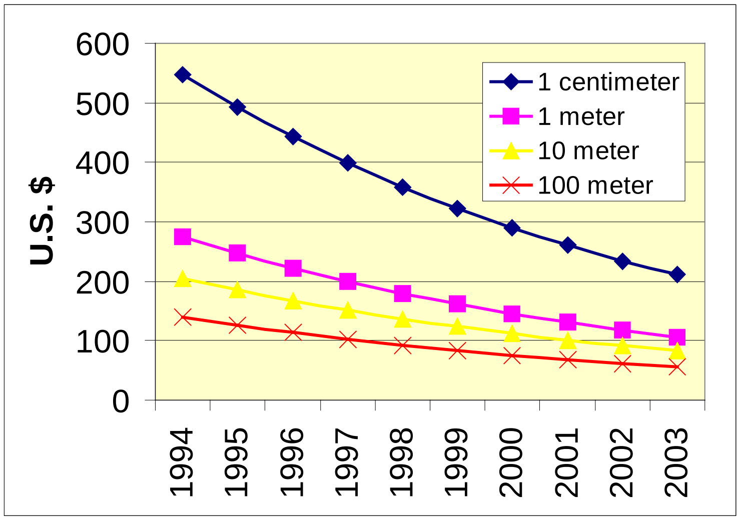

Figure 1: Price Development of GPS Module Cost by Accuracy
(After NAPA/NRC, 1995)

Considering these market projections shown in Figure (1), it is very difficult for any other positioning and navigation technology that to compete with GPS (Schwarz and El-Sheimy, 1999). Therefore, other navigation technologies would typically be developed for 'non-GPS' environments, i.e. for environments where GPS does not function at all (underground, underwater, in buildings) or where it performs poorly (forested areas, urban environments). Although there is still a substantial navigation market for 'non-GPS' environments, it is much smaller than the one predicted for GPS. In the portion of the market where GPS is only available for part of the time, the question will be 'how much is the user willing to pay for a continuous navigation solution'? This obviously will depend on the specific application and it might be possible that niche markets will develop around such applications. Integrated solutions will be of high interest in such applications, and may involve sensor integration as well as data base integration for applications such as map matching. In those applications where GPS does not work at all, the search for cost-effective alternatives will continue.

One promising development is the emergence of Micro-Electro-Mechanical Systems (MEMS) technology. MEMS is an enabling technology with a massive global market, predicted to be at 140 billion US $ in 2002. This means that it will have about 7 times the market size of GPS at that time. A small portion of this market, about 2%, will support inertial sensor technology. Since INS technology is capable of working in all environments where GPS has difficulties, MEMS inertial technology is seen as both a possible complement of GPS technology and a potential alternative to GPS if market volumes develop in the way anticipated, for more details see DARPA (1998), and U.S. D.o.D. (1995).

Besides the MEMS technology development, there is also an increasing trend towards integrated systems. The integration of GPS with low-cost IMUs has already reached the product stage. Such systems can either be used as a highly reliable navigation systems, giving position, velocity, and attitude with high accuracy, or as a georeferencing systems for various imaging sensors (optical or digital cameras, laser scanners, multispectral scanners). Integration of low-cost sensors, specifically for backpack systems has also made considerable advances. The use of vision-based systems in conjunction with low-cost position and attitude sensors may become a viable alternative in cities if current advances in enabling technologies continue. Specifically the development of digital cameras on a C-MOS chip, the availability of inexpensive storage devices of Gigabyte capacity, and the increase in computer speed to 1000 MHz. Will contributes to the emergence of low-cost vision-based systems (Schwarz and El-Sheimy, 1999).

3. STATUS OF CURRENT INTEGRATED SYSTEMS

The GPS is capable of providing positioning and navigation parameters in all situations where uninterrupted signal reception is possible and the general satellite geometry is within acceptable limits. It is also evident that other navigation technologies are currently not capable of providing similar accuracies at a comparable price, i.e. there is not real competition to GPS in a scenario of uninterrupted signal reception. This leaves two scenarios to be considered. The first one is that of intermittent signal reception, as for instance in heavily forested areas or in urban centers. The other one is that of no signal reception at all, as for instance in buildings, underground or underwater. In the first case, GPS has to be integrated with other navaid sensors to bridge periods of no signal reception. In the second case, GPS has to be replaced by another system that can provide continuous navigation in those environments where GPS does not work. In terms of systems, both INS and vision-based systems (mainly for robotics applications) are the most commonly used systems. In terms of navaids, odometers, gyros and digital maps will be considered for land vehicle navigation, and pedometers, magnetic compasses, digital maps, and cellular phones for backpack systems.

The integration of the navigation technologies (GPS, INS, and vision-based technologies) with navaids provides a system that has superior performance in comparison with either a GPS, an INS, or vision-based stand-alone system. For instance, GPS derived positions have approximately white noise characteristics over the whole frequency range. The GPS-derived positions and velocities are therefore excellent external measurements for updating the INS and providing the imaging sensors with position parameters, thus improving its long-term accuracy. Similarly, the INS can provide precise position and velocity data for GPS signal acquisition and reacquisition after outages and the orientation parameters for the vision-based system. The vision-based system can be used as a backup navigation system and to update the

INS data if the GPS signal is blocked for long periods. In general, the fact that redundant measurements are available for the determination of the vehicle trajectory parameters greatly enhances the reliability of the system.

The navigation states vector (position, velocity, and attitude) can be determined by judicially combining elements of: navigation technologies (e.g. GPS, Inertial, and vision-based) and navigation aids (e.g. distance, velocity, and attitude sensors). This is shown in Figure (2) where the navigation technologies and navaids are listed in two blocks. Table (1) lists current and possible integrated systems scenarios. Table (2) lists which sub-vectors of the Navigation State that can be obtained with these systems scenarios and which characteristics and the resulting integrated system will have. Possible applications are then given in the last column.

The Tables indicate that a wide variety of integration strategies can be implemented. Each has its own characteristics and the choice of a specific system will be based on system requirements and applications. Although it is possible to integrate any set of technologies, the integration of GPS and INS represents the core of for any integrated systems where reliability and versatility are the major issues. The low cost of GPS receivers, the coverage and reliability of GPS, and the expected decrease in cost of MEMS-based inertial sensors make GPS and INS the logical technologies for realizing the benefits offered by integrated positioning systems. Many companies are currently working on the integration of MEMS based IMU with GPS, with projections of size, weight and power at 2 x 2 x 0.5 cm, 5 g, and less than 1 W for implementation at the ASIC level.

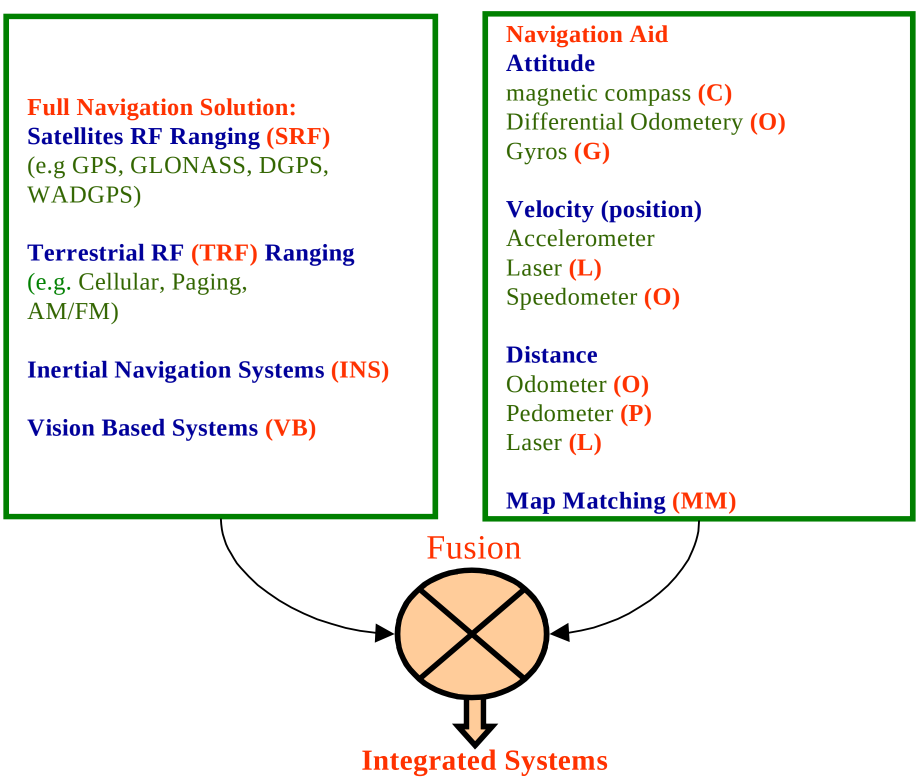

Figure 2: Concept of Integrating Navigation Systems and Navaids.

Table 1: Integrated Systems Scenarios

Scenario		Navigation Systems				Navigation Aids (navaids)							Application	
		SRF	TRF	VB	INS	MM	L	O	P	C	G	A	Vehicle	Backpack
Current Systems	**1**	√	√										√	√
	2	√			√								√	√
	3	√		√	√								√	
	4	√				√							√	
	5	√						√			√		√	
	6	√							√	√		√		√
	7	√					√				√		√	√
Possible Systems	***8***	√		√							√			√
	9	√		√			√				√			√
	10*	√						√					√	
	11	√					√			√				√
	12		√			√							√	
	13		√					√			√		√	
	14		√						√	√		√		√

Table 2: Characteristics, Limitations, and Applications of Systems Scenarios
(* Provides heading only)

Scenario	Navigation State			Characteristics/Current Limitations	Applications	
	r(t)	v(t)	R(t)		Vehicle	Backpack
1	√	√		• Low cost/lightweight system • Signal blockage in urban centers	Car navigation Fleet Management	Hikers Rescue operations
2	√	√	√	• Works in all environments • High Cost/Weight	Military Navigation Mapping	Seismic Applications
3	√	√	√	• Works in all environments • High Cost/Weight	Highway inventory systems	
4	√	√		• Low cost/lightweight system • Signal blockage in urban centers	Car navigation	
5	√	√	√*	• Low cost/lightweight system • Provides heading only • Signal blockage in urban centers	Car navigation	

6	√	√		• Low cost/lightweight system • Signal blockage in urban centers		Navigation
7	√	√	√*	• Static mode of operation for backpack • Provides heading only	Mapping applications	Mapping applications
8	√	√	√*	• Static mode of operation • Provides heading only		Mapping applications Target tracking
9	√	√	√*	• Static mode of operation • Heading only		
10	√	√		• Low cost/lightweight system • Signal blockage in urban centers	Car navigation	
11	√	√	√*	• Provides heading only • Signal blockage in urban centers		Targeting tracking
12	√			• Low cost/lightweight system • Local coverage • Provides heading only	Car navigation	
13	√		√*	• Low cost/lightweight system • Local coverage • Provides heading only	Car navigation	
14	√	√	√*	• Low cost/lightweight system • Local coverage • Provides heading only		Navigation

3. FUTURE TRENDS

The trend towards integrated systems in positioning and navigation is fuelled by the demand for high accuracy, lightweight, low cost, and by technological developments which satisfy this demand. Three developments are especially important in this context: the progress in MEMS based INS systems, future enhancement to GPS, and future trends of vision-based systems and map matching. There is no question that that GPS will be part of any future integrated system, if GPS signals can be received for at least part of the time

The Progress in MEMS Technology: The Progress in MEMS Technology will enable in the near future complete inertial navigation units on a chip, composed of multiple integrated MEMS accelerometers and gyroscopes. In addition to single-chip inertial navigation units, there are many opportunities for MEMS insertion into low-power, high-resolution, small-area displays and mass data storage devices for storage densities of terabytes per square centimeter. These opportunities are essential if vision based systems are to be fully integrated into a backpack integrated navigation system.

Figure (4) relates the predicted development of MEMS-based inertial sensors to three major performance parameters - bias, scale factor and noise. These parameters are usually considered when judging system accuracy. They show that, for the medium term, two conclusions are possible at this time. First, MEMS-based inertial sensors will in general reach higher performance levels than the MEMS-based IMU-on-a-chip. This simply indicates that performance is dependent on the physical dimensions of the sensor or system. Second, it appears possible that MEMS-based tactical IMUs will become a reality within a ten-year time frame, but that navigation-grade systems are rather unlikely during that period. For more details see Schwarz and El-Sheimy (1999), Barbour (1996), and Allen et. al. (1998).

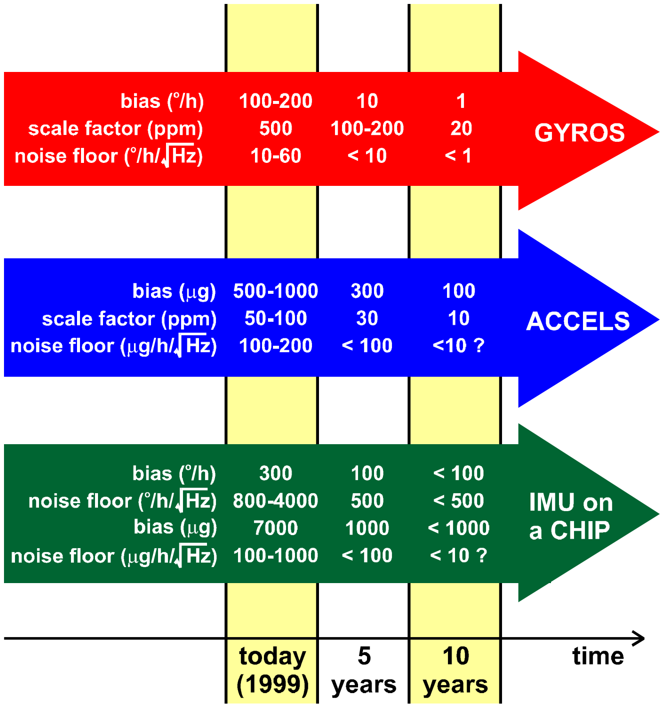

Figure 4: Predicted Development of MEMS-Based Inertial Sensors

The Future Enhancement of GPS: The proposed enhancements to GPS have the common goal of increasing both the capability and robustness of the system. The possible major modifications to the system include the removal of the intentional degradation of the signals (SA), the introduction of new signals, improvements in the control segment functions and increases in the size of the GPS constellation. The potential effects of these have been lumped together and are shown in Figure (4). It is estimated that they will improve the 2DRMS to about 9.5m. These are long-term goals and no firm commitments have yet been made.

Figure (5) shows the following (for more details see Schwarz and El-Sheimy, 1999 and NAPA/NRC, 1995 report):

- Removal of SA: the removal of SA will improve the 2DRMS accuracy from 101.4 to 32.5m.
- New signals: under conditions of no SA, dual frequency corrections improve the 2DRMS from 32.5m to 16.6m.
- Increasing the Size of the GPS Constellation: this would result in an improvement of the 2DRMS from 9.5m to 7.1m, assuming that all of the other potential improvements named above have been implemented.

Increasing the Size of the GPS Constellation: this would result in an improvement of the 2DRMS from 9.5m to 7.1m, assuming that all of the other potential improvements named above have been implemented.

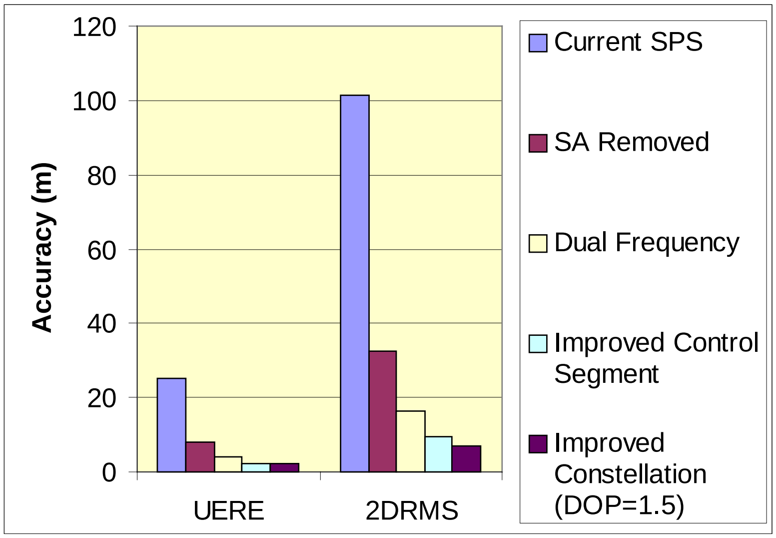

Figure 5: Improvements in GPS Single Point Accuracy Due to Potential Improvements (Average DOP = 2.0 Unless Otherwise Marked).

Future Trends of Vision-Based Systems and Map Matching Techniques: Conceptually, the vision-based concept is very attractive. Current experimental systems are limited in range and are oriented towards robotics applications. Figure (6) shows the future trend in digital cameras prices, resolution, and weight. The price and weight are going down while the resolution is going up. VBS hardware (digital cameras, storage devices, portable computers) could currently support the development of an autonomous VBS at the level of 10K US$ and a weight less than 2 kg. This indicates that low-cost and lightweight systems based on digital cameras are feasible. The major challenges are algorithms and software that make their use in unstructured environments possible. Smart image matching and 3D modeling of the VBS environment are not at a stage to support such a development. What complicates the problem is that the currently market demand for a stand-alone VBS is limited.

Because of these problems, its not expected VBS will be implemented as stand-lone navigation system in the next 5 years that but rather as a component of an integrated system. Possible scenarios include GPS and INS. The integration of GPS/INS with vision systems has been used in a number of post-mission mapping applications (El-Sheimy, 1996, and Schwarz, 1998). The current limitation for their implementation as autonomous navigation systems for land and backpack systems is mainly due the size, weight, and cost of GPS and INS. The integration of VBS with MEMS-based tactical-grade IMU and a GPS chip can be seen as one solution to this problem. The exterior orientation parameters can in this case be determined by a combination of GPS and INS. The result is a series of georeferenced images, i.e. of images with their six parameters of exterior orientation 'stamped' on them. Once, this stamp has been put on the image, the time dependence has been eliminated, i.e. each image has a unique position and orientation in space. Therefore, the major part of image matching and modeling the 3D environments around the system is rather simple. Whether a prototype system can be built in the next 5 years will mainly depend on the cost of the MEMS-based tactical grade IMU. In a 10-year period such scenario will be more feasible as the cost of MEMS-based tactical-grade IMU will be at the level of $500-$1000. The second scenario is a navaid-based backpack system, which if foreseen to happen within the next 5 years. It will ingrate a VBS with navaid such as pedometers and compass (Judd, 1997). Current backpack systems that integrate GPS, pedometer, altimeter, and compass already exist. Their cost is about $2000 and their weight less than 3 oz.

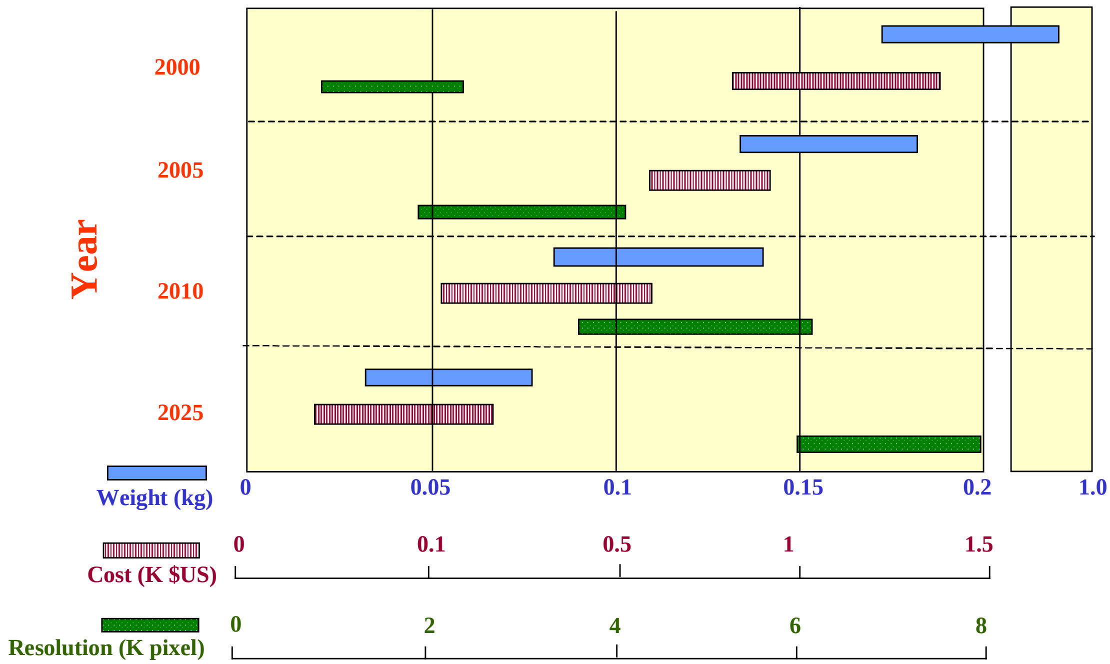

Figure 6: The Trend in Digital Cameras Prices, Resolution, and Weight

Although there are some problems with map matching, it has a number of advantages and is used in 25% of systems surveyed by Krakiwsky (1996). The map matching system is relatively inexpensive as it only requires cheap sensors, such as the odometer and/or the ABS (Anti-lock Braking System) pulses. There is no external infrastructure required and the accuracy of the system is fundamentally limited by the accuracy of the digital maps and the matching algorithm. Successful map matching is reliant upon maps that are complete and accurate to better than 30m absolute. This is becoming less of a problem as companies such as Navtech/EGT and Etak in the USA, Teleatlas in Europe, the Japan Digital Road Map Association, and Geographic Technologies (Telstra) in Australia have accurately mapped or plan to map the major cities, urban areas, and major highways in their region of interest. Finally, the development of portable navigation systems that are map-based should increase with the availability of less expensive, more intelligent digital road maps. A map-based personal navigation assistant (PNA) that supports path finding and route guidance for backpack applications is another development that may not be too far away.

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REFERENCES

Allen, J.J, R.D. Kinney, J. Sarsfield, M.R. Daily, J.R. Ellis, J.H. Smith, S. Montague, R.T. Howe, B.E. Boser, R. Horowitz, A.P. Pisano, M.A. Lemkin and A.C.T. Juneau (1998): "Integrated Micro-Electro-Mechanical Sensor Development for Inertial Applications", Proceeedings of IEEE PLANS 1998, pp. 9-16.

Barbour, N. (1996): "Status of Inertial Systems", Paper presented at ION National Technical Meeting January 22-24, 1996, California.

Charting the Future (1995): A report jointly sponsored by the National Academy of Public Administration (NAPA) and the US National Research Council (NRC).

DARPA (1998): "Microelectromechanical Systems (MEMS) ", Electronics Technology Office, DARPA, http://web-ext2.darpa.mil/eto/mems/index.

Judd, T., (1997): "A personal Dead Reckoning Module", ION GPS'97 meeting, Kansas City, MO, USA.

Krakiwsky, E. J., (1996): "Assessment of Positioning and Navigation Technologies for Intelligent Transportation Systems", A report prepared for TRANSPORT CANADA and INDUSTRY CANADA, Aerospace and Defense Branch, by Intelligent Databases International Ltd., Calgary, Canada

Nexus Market Analysis Task Force Issues Market Study Report on MEMS/MST (1998), Micromachine Devices Magazine, Vol. 3, No. 10, October 1998, pp 1-5.

Schwarz, K.P. (1998): "Mobile Multi-Sensor Systems - Modelling and Estimation", Proc. of the Int. Symp. on Geodesy for Geotechnical and Structural Engineering, Eisenstadt, Austria, April 20-22, 1998, pp 347-360.

Schwarz, K.P. and El-Sheimy, N. (1999): "Future Positioning and Navigation Technologies" Study performed under the Scientific Services Agreement with Batelle, Columbus Division and Topographic Engineering Center, Fort Belvoir, VA, USA.

U.S. D.o.D. (1995): "Microelectromechanical Systems Opportunities", A Department of Defense Dual-Use Technology Industrial Assessment.

BIOGRAPHICAL NOTES

Dr. Naser El-Sheimy – is an Assistant Professor at the Department of Geomatics Engineering of the University of Calgary. He holds a B.Sc. and M.Sc. from Egypt, two post-graduate Diplomas in Photogrammetry and Remote Sensing from ITC, the Netherlands, and a Ph.D. from the University of Calgary. His area of expertise is the integration of GPS/INS/imaging sensors for mapping and GIS applications with special emphasis on the use of multi-sensor in Mobile Mapping Systems. He is now the chairman of the special study group for Mobile Multi-Sensor Systems of the International Association of Geodesy and the chairman of The International Federation of Surveyors (FIG) working group C5.3 on "kinematic and Integrated Positioning Systems”

APPENDIX

Report on the Major Activity of the WG 5.3: The 3rd International Symposium on Mobile Mapping Technologies

Nearly six years ago, the Ohio State University hosted the first International Symposium on Mobile Mapping systems. At that time, it was very clear that Mobile Mapping had the potential for providing a diversity of services and products to the mapping community. The Second International Symposium, which took place in Bangkok, Thailand in 1999, provided further evidence – the quality and diversity of papers and the number of attendees further proved that Mobile Mapping was an area of research of its own that deserves a separate symposium. Since then, substantial progress has been made in the area of Mobile Mapping technologies, progress that would not have been anticipated six years ago.

The 3rd International Symposium on Mobile Mapping Technology was successfully held in Cairo, Egypt, January 3-5, 2001. It was co-organized by Ain Shams University, Egypt, the ISPRS Commission II (WG II.1 "Real time Mobile Mapping"), the FIG Commission V (WG 5.3 "Kinematic and Integrated Positioning Systems"), the IAG Special Commission IV (WG SC4.1 "Mobile Multi-Sensor Systems "), The University of Calgary, the Egyptian Survey Authority and the Chinese National Lab for Information Engineering in Surveying, Mapping and Remote Sensing for sponsoring the symposium. The symposium was financially supported by Ashtech-Magellan Corp. (USA/UK), Applanix Corp. (Canada), and Premier GPS Inc. (Canada).

The symposium provided a stimulating casual environment to promote scientific presentations, interactive discussions, and information exchange. It brought together 350 participants from 29 countries, who are specialists, engineers, users and those interested in mobile mapping technology, kinematic real-time positioning, sensor integration and calibration, feature extraction and 3-D data acquisition. 90 oral presentations in 18 sessions reported most recent R&D and application achievements of mobile mapping. The proceedings of the symposium, edited by Dr. Naser El-Sheimy, have been produced in a CD and can be ordered from the Department of Geomatics Engineering, The university of Calgary (E-mail Marguerite Anderson: marguerite@geomatics.ucalgary.ca).

The opening ceremony was chaired by Dr. Naser El-Sheimy, Convenor, and included welcome speeches by representatives of the sponsoring organizations, followed by welcome speeches by Prof. Mohamed Sheriah, the Dean of Faculty of Engineering of Ain Shams University, Prof. Hassan Ghallab, President of Ain Shams University, and Prof. Ibrahim El-Domery, the Egyptian Minster of Transportation (See Picture 1). Prof. Gerard Lachapelle gave a very informative keynote address on "Location: A 21st Century Utility" where he described how location and navigation technology, user requirements and new applications drive each other, with the users as the major beneficiaries. Gerard predicted that personal location and navigation applications would capture a large share of the location and navigation markets in the decade ahead.

"The exciting technical program was complemented by a most interesting and educational social program that included a night cruise on the river Nile, a Sound and Light show at the Pyramids and individual visits to the countless historical sites of Cairo. Cairo is the oldest lived-in city in the world and is an historical treasure trove. The Egyptians are keenly aware of their own and other cultures and were most gracious hosts" said Gerard Lachapelle.

Picture 1: From Left: Prof. Hassan Ghallab, President of Ain Shams University, and Prof. Ibrahim El-Domery, the Egyptian Minster of Transportation, Prof. Mohamed Sheriah, the Dean of Faculty of Engineering of Ain Shams University, Dr. Naser El-Sheimy, Convenor of the Symposium.

Picture 4: Front left: Dr. Naser El-Sheimy, Dr. Ibrahim Shaker, Prof. Jean-marie Becker, Prof Mohamed Sheriah
Back left: Mikael Lilje, Dr. Atef Fayad, Prof. Gerard Lachapelle, Prof. Adel Hagag

The symposium was structured in such a way that features common to all Mobile Mapping Systems (MMS) were treated first before specific application, new applications, and trends in MMS were considered. Common features included the mathematical framework of direct georeferencing for land and airborne imaging sensors, kinematic positioning, object extraction and recognition, and estimation techniques common to all MMS. Only after these common features have been treated, specific sessions were dedicated to cover the full spectrum of Mobile Mapping Technology. The following highlights the major features of papers presented at the symposium; they can be categorized as follows:

Papers on Mobile Mapping Systems:

It was very clear from the number of papers presented at the symposium that building a mobile mapping system by integrating off-the-shelf hardware and software components is getting easier, but it requires significant courage, investment and efforts. The symposium witness development activities by many universities and companies on almost all continents. Land-based systems continue to demonstrate the power promised at the early time of the development, for example in road and railway survey, utility survey and others. The takeover of the part of such traditional surveying markets is believed to be only a start. Meanwhile, the very same concept has been transferred to airborne and backpack systems where positional and orientational sensors are integrated with imaging sensors to approach real-time mapping that is not restricted to where only land vehicles can reach. The "dream" is to achieve the same level of ground position accuracy as traditional aerial triangulation. The following table summarizes some of the characteristics of the systems presented during the symposium.

System	Positioning			Imaging		Other
Name / Developers[1]	GPS	INS	DR	CCD	VHS	Sensors
Land Systems (Van, Railway, etc.)						
GPS Van/ OSU	✓		✓	2	2	
KISS/UBW	✓	✓		2	1	
LD2000-R /UW	✓		✓	2	1	
Visimind's MMS / Visimind AB (for both land and airborne applications)	✓	*		2		*Orientation sensors
Portable MMS / UofC	✓	*		1		*Orientation sensors
VISAT - UofC/VTI	✓	✓	✓	8		
Moses / UFAF	✓	✓		2	1	Pointing laser
Airborne Systems						
AIMS – OSU	✓	✓		1		
Dual Camera/ UofC	✓	✓		2		
3-linear scanner/ IFP, Stuttgart	✓	✓		3*		* line scanner
ALMIMS/ CAS	✓	✓		1*		*multi-spectral imaging scanner + LIDAR

Star-3i / Intermap Technologies Corp	✓	✓				IFSAR
DORIS / ARC	✓	✓		1		LIDAR

[1] **OSU:** Ohio State Univ., **UFAF:** University of the Federal Armed Forces, **UBW:** Univ. der Bundeswehr Munchen, **UW:** Wuhan University , **AUT:** Aachen Univ. of Technology, **JECA:** John E. & Chance, **UofC:** The Univ. of Calgary, **ARC:** Alberta Research Council , **CAS:** Institute of Remote Sensing Applications of Chinese Academy of Sciences

Papers on New Developments and Applications of Mobile Mapping Systems

Some of new developments and applications presented during the symposium are:

New Development

1. Helicopter Based Portable Handheld MMS for Avalanche Mapping: The system is developed by the Photogrammetric lab of the Institute of Geomatics at Swiss Federal Institute of Technology. It integrates light aerial camera and GPS/INS components to a platform that is free of the helicopter in 6 degrees of freedom. Experimental studies performed in the avalanche test site of "Vallée de la Sionne" allow determining the correct ratio between the system accuracy versus its flexibility. Experiments performed during the last two years in "Vallée de la Sionne" avalanche test site showed that helicopter based photogrammetry is able to provide snow volume measurements with an accuracy of 20-30cm when good conditions for accurate exterior orientation and contrast are fulfilled.
2. A Portable MMS For the Survey Community: The system is developed by the Department of Geomatics Engineering at the University of Calgary. The goal of the system development is to overcome the drawbacks of current mobile mapping systems - namely their high cost, large size, and complexity - which have restricted their widespread adoption in the survey industry. The development of such a system satisfies the demand for a mobile mapping system that can compete both cost-wise and in user friendliness with current backpack GPS systems and conventional terrestrial survey systems, while realising the significant gains in efficiency typical for MMS. The system integrates a digital magnetic compass, dual-frequency GPS receiver and consumer digital camera into a multi-sensor mapping system. First system testing indicate that with three images at a 20m object-to-camera distance, absolute accuracies of under 25 cm are achieved. This is comparable to current single-frequency GPS data acquisition systems. The internal agreement of points surveyed using the system is under 10 cm.
3. Airborne Laser-ranging and Multi-spectral Imaging Mapping System (ALMIMS): The system is a multi-sensor mapping system developed by the Institute of Remote Sensing Applications of Chinese Academy of Sciences. It is integrated with multi-spectral imaging scanner, laser ranging scanner, Global Positioning System (GPS), and Inertia Navigating System (INS), all of which are tightly coupled and synchronized, insuring the pixel-level correspondence of image and laser ranging points. The result is a high-resolution multi-spectral image overlapped with laser ranging grids at certain intervals. It can produce ortho-rectified image, digital surface model, contour map, and perspective map at near real-time without ground control

points. It can be used for automatic buildings/tree extraction, and semi-automatic roads tracing.

4. DORIS (Differential Ortho-Rectification Imagery System): DORIS is an airborne multi-sensor mapping system which has been under development for years at Alberta Research Council. DORIS combines a laser-scanning technology with digital imaging technology to produce high-resolution and highly accurate ortho-rectified planimetric image map. The focus of DORIS is on acquiring data for fundamental biophysical entities of sustainable forest eco-systems and reducing the cost of the planning and conduct of forest operations.

New Applications:

1. Automatic Bald Digital Terrain Model Reconstruction from Digital Surface Data Acquired from an Airborne SAR System: Two approaches for automatic reconstruction of bald DTMs from Digital Surface Models (DSMs) are presented in this paper; namely hierarchical and non-hierarchical approaches. The non-hierarchical approach is mainly used for urban areas while the hierarchical approach is suitable to different terrain types and data with different spatial resolutions. Test results show that for the hierarchical approach the accuracy of the reconstructed bald DTM, when referenced against bald terrain surface models generated from a Lidar mapping system, is typically less than 1.25 meters RMSE in urban and low mountain areas. This is obviously an acceptable result as the accuracy of the original SAR DSM is at 1-2 meter (RMSE) level.
2. Automatic Generation of a Hierarchical DEM for Mars Rover Navigation: This paper presents techniques for the generation of a hierarchical DEM using descent and rover imagery for Mars mapping and rover localization. During a descending process of a Mars spacecraft, ten descent images may be taken at approximately every half of the altitude. The images can be used to generate an initial DEM of the landing site. The paper proposed a further refinement technique for the DEM both in accuracy and resolution to form a five-layer hierarchical DEM, with the resolution ranging from one centimeter in the immediate area of the landing center to one meter in the boundary region about 1 km away from the center. The DEM is generated by using the hierarchical descent images with an increasing sequence of resolutions. The produced hierarchical DEM can be used for an interactive system to assist rover traverse design and for landmark extraction for automatic Mars rover localization. The authors mentioned that in future research, the rover images will also be used to expand the hierarchical DEM as the rover traverses farther from the landing center. The DEM will be refined and expanded as more new rover images become available.
3. Integrating Data From Terrestrial Mobile Mapping Systems And Aerial Imagery for Change Detection Purposes: Data fusion from different sources is one of the key problems facing the photogrammetric and computer vision research communities. In this paper, a new approach for combining data from terrestrial Mobile Mapping Systems (MMS) and aerial imagery. Road network data, captured by a MMS, is used to determine the Exterior Orientation Parameters (EOP) of an aerial image - Single Photo Resection (SPR).
4. Integrating photogrammetric data from mobile ship-borne and airborne systems for support conservation process, and environmental analysis of cost heritage along the “CinqueTerre” coast in the Gulf of Liguria region, Italy: The project is directed to

emphasize the environmental heritage, on which Levanto and Bonassola base their own tourist economy, focusing the guide lines and the analysis required for the landscape insertion of the recovering project of the old railway tunnel faced to the seacoast, work over land and work over sea, through 3D virtual navigation on the gulf of Levanto and on urban centre.

5. Automatic Building extraction from airborne laser systems: This paper introduces a series of building extraction techniques in compatible with Airborne Laser-ranging and Multiple-spectral Imaging Mapping System (ALMIMS), including shadow-based method for large buildings in urban area with sparse laser ranging points, and direct laser-point segmentation method for buildings in rural area. These techniques perform well in semi-real-time, thus provide a fast data source for GIS system.
6. Integration of Mobile Phone Location Services into Intelligent GPS Vehicle Navigation Systems: GPS for position determination in vehicle navigation systems in stand alone mode works quite well only for open areas. It is obvious that in the case of obstruction of satellite-receiver visibility either position accuracy is bad or no position determination is possible. Especially in cities with high-rise buildings, satellite visibility is a very critical issue for intelligent vehicle navigation systems. Therefore GPS positioning has to be combined with other methods, e.g. dead reckoning (DR) and map matching. Apart from this, other new technologies are available nowadays which can also be employed in navigation systems. In particular, mobile phones of the next generation, the so-called 3G (Third Generation) phones, will provide the ability to determine the location of any mobile phone subscriber anywhere, anytime, with a precision required for navigation systems. Thereby different strategies for position determination can be employed. It is claimed that the position fix can be obtained with an accuracy in the order of ± 125 m using current technologies in the widespread second generation GSM network. For the use of 3G mobile phones in the UTMS network, however, an increase in accuracy for the position determination by a factor up to 10 is expected. In this paper, preliminary results on the integration of mobile phone location services for temporary position determination into the system design is investigated.

Papers on Emerging Processing Techniques for Mobile Mapping Systems

The continual development of Mobile Multi-Sensor Systems (MMS) is stimulating the development of intelligent processing techniques and new areas of application. Advanced techniques such as neural networks and snake models are currently under development to automate the measuring procedures and automatic object recognition from mobile mapping data. The two unique advantages of MMS-generated data:

- Images have unknown exterior orientation parameters, and
- The image sequences are along a known path

These two advantages make the automation of object recognition and measuring procedures more efficient and robust. The science of multiple image based matching has found its application in the mobile mapping processing. Bayesian networks have been actively researched and promise great potential for feature extraction. Real-time automation, in our opinion, remains to be the future of processing techniques for MMS. Some of the emerging processing techniques presented during the symposium are:

1. Motion estimation by Vision for Mobile Mapping with a Motorcycle: In this paper a vision algorithm to estimate the angular velocity of a motorcycle was introduced. This estimate, integrated with the measurements provided by other sensors such as a speedometer allows for a complete reconstruction of the trajectory followed by a motorcycle. The proposed scheme is, then, a valid alternative to the use of costly inertial platform to compensate for missing GPS data in order to geo-register information gathered by on-board sensors.
2. Motion Tracking Framework for Mobile Appliances: Mobile appliance, which includes hand-held and portable devices, suffers from a limitation of portable power source (battery) and a limitation of communication bandwidth for wide area applications. This paper presents a new framework for object motion tracking. The proposed technique reduces the computational of the motion tracking algorithm as well as the number of bits that represents the object.
3. Online GIS Module for an Unmanned Aerial Vehicle: This paper provides an overview on how GIS could contribute to the navigation tasks of an unmanned autonomous aerial vehicle (UAV) and to the predictive capabilities required for identifying and tracking vehicles on the ground. The paper presented preliminary studies related to a project at Linköping University, Sweden. The project is an ambitious, long-term basic research project with the goal of developing technologies and functions necessary for the successful deployment of a fully autonomous UAV operating over diverse geographical terrain containing road and traffic networks.
4. Innovative Active-Vision-Based Approach for Traffic Surveillance and Control: ITS is an emerging global industry that capitalizes on advanced technologies to better manage the dynamic, over-congested transportation networks of today. The current ITS boom has given rise to the need for a comprehensive real-time surveillance of traffic conditions over the transportation network to allow for dynamic control and management of traffic. Existing traffic detection technologies cover a wide spectrum of technologies as well as performance, ranging from modest pavement-buried inductive loop detectors to more advanced pole-mounted off-road detectors such as microwave, radar, and camera-based detectors. All existing detector types, however, share a common limitation of being point-detectors reflecting only traffic conditions at the locations of the detectors. This paper discusses research-in-progress to develop a mobile, bus-mounted machine vision technology for transit and traffic monitoring in urban corridors, as required by Intelligent Transportation Systems (ITS).

The technological development is still very rapid and major contribution in the area of MMS can be expected in years to come. The symposium shows a wide variety of applications including mapping, GIS, tracking, and navigation. Once different user group better understands the potential of these techniques, a further diversification of applications areas can be expected. However, continued research and commercial development of mobile mapping systems, depends on the success in implementing potential applications, creating new markets and stimulating demand for this technology.

The next International Conference on Mobile Mapping Technology will be held Coming, China, August 12-14, 2003. For further information please contact Prof. Dr. Deren Li, Wuhan

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Relevant Literature:

1. Ash, T., Silva, R., Brown, A., and LaMance, J. (1995), "GPS/Inertial Mapping (GIM) System for Real Time Mapping of Roadways Using WADGPS", Proceedings of the Institute of Navigation, ION GPS-95, Palm Springs, CA, USA, September 12-15, pp. 1825-1830.
2. Baraniak, D. W. (1994), "Creating High Accuracy Digital Maps Using GPS and Stereo Digital Imaging Technologies", Wisconsin Professional Engineer, Published by The Wisconsin Society of Professional Engineers, May/June 1994, Vol. 35, No. 4, pp. 12-14.
3. Benning, W. Mobile mapping by a car driven survey system (CdSS), The International Symposium on Kinematic Systems In Geodesy, Geomatics and Navigation, Eisenstadt , Vienna, Austria, April 20 to April 23, 1998.
4. Blaho, G. and Toth, C. (1995), "Field Experience With a Fully Digital Mobile Stereo Image Acquisition System", The Mobile Mapping Symposium, Columbus, OH, USA, May 24-26, 1995, pp. 97-104.
5. Bossler J. D, Goad, C. and Novak, K. (1993), "Mobile Mapping Systems; New Tools for the Fast Collection of GIS Information", GIS'93, Ottawa, Canada, pp. 306-315, March 23-35.
6. Cramer, M., J. Skaloud, K.P. Schwarz (1996). Exterior Orientation by Direct Measurement of Camera Position and Attitude. XVIII. ISPRS Congress, Vienna, July 9-19, 1996, Int. Archives of Photogrammetry and Remote Sensing, vol. 31, part B3, 125-130.

7. Dorota A. Grejner-Brzezinska and Charles Toth, Direct Platform Orientation in Aerial Surveying Practice, the International Workshop on Mobile Mapping Technology, Bangkok, Thailand, April 21-23, 1999
8. El-Sheimy N. and Schwarz K. P., "A Unified Approach to Multi-sensor Integration in Photogrammetry", Invited paper, ISPRS Joint Workshop on Integrated Acquisition and Interpretation of Photogrammetric Data, November 8-10, 1995, Stuttgart, Germany.
9. El-Sheimy, N., "The Development of VISAT - A Mobile Survey System for GIS Applications", Ph.D. Thesis, Department of Geomatics Engineering, The University of Calgary, UCGE Report No. 20101.
10. El-Sheimy, N., Schwarz, K.P. , Lavigne, M., "Expert Knowledge System for Mobile Mapping Applications", The International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation, KIS97, Banff, Canada, June, 1997
11. El-Sheimy, N. and M. Lavigne, "3-D GIS Data Acquisition Using GPS/INS/Video Mobile Mapping System", The International Symposium on Kinematic Systems In Geodesy, Geomatics and Navigation, Eisenstadt , Vienna, Austria, April 20 to April 23, 1998.
12. El-Sheimy, N. and Schwarz K.P., " Navigating Urban Areas by VISAT - A Mobile Mapping System Integrating GPS/INS/Digital Cameras for GIS Applications", the USA Institute of Navigation Journal, 1998.
13. El-Sheimy, Naser, Mike Chapman, and V. Tao, "An Intelligent Mobile Mapping System", the International Workshop on Mobile Mapping Technology, Bangkok, Thailand, April 21-23, 1999
14. Lohr , U. , TopoSys laserscanner system, The International Symposium on Kinematic Systems In Geodesy, Geomatics and Navigation, Eisenstadt , Vienna, Austria, April 20 to April 23, 1998.
15. Mostafa, M.M.R., K-P Schwarz, and P. Gong (1997). A Fully Digital System For Airborne Mapping. Proceedings of The International Symposium on Kinematic Systems In Geodesy, Geomatics, and Navigation, Banff, Canada, June 3-6, 463-471.
16. Mostafa, M.M.R., K-P Schwarz, and M.A. Chapman (1998). Development and Testing of an Airborne Remote Sensing Multi-Sensor System. ISPRS-Commission II, Symposium on Data Integration: Systems and Techniques, Cambridge, UK, July 13-17, 1998.
17. Schwarz K.P. and N. El-Sheimy," Georeferenced Video Images For GIS Applications in Urban Centers", Proceedings of the Workshop "Integrated Sensor Orientation, Theory, Algorithms, and Systems", WICHMAN (ISBN 3-97907-279-05), Ed. Colomina/Navarro, 1995, pp. 78-90.
18. Schwarz, K.P (1995) , "Integrated Airborne Navigation Systems for Photogrammetry" The Wichmann Verlag, ISBN 3-87907-277-9, Photogrammetric week'95, Stuttgart, Oberkochen, Germany, pp. 139-153.

19. Schwarz, K.P. and El-Sheimy, N., (1996), "Kinematic Multi-sensor Systems For Close Range Digital Mapping" , ISPRS 1996, Commission V, Working Group III, Vienna, Austria, July 9-19, 1996, Invited Paper.

20. Schwarz, K.P. and J. Sun (1998). Development and Testing of a Real-Time DGPS/INS Integrated System. ISPRS-Commission II, Symposium on Data Integration: Systems and Techniques, Cambridge, UK, July 13-17, 1998 (in print).

21. Skaloud, J., Y.C. Li and K.P. Schwarz (1997). Airborne Testing of a C-MIGITS II - Low Cost Integrated GPS/INS. International Symposium on Kinematic Systems in Geodesy, Geomatics and Navigation - KIS97, Banff, Alberta, Canada, June 3-6.

22. Skaloud, J. and K.P. Schwarz (1998). Accurate Orientation for Airborne Mapping Systems. ISPRS-Commission II, Symposium on Data Integration: Systems and Techniques, Cambridge, UK, July 13-17, 1998.

23. Sternberg, H., W. Caspary, H. Heister Determination of the trajectory surveyed by the mobile surveying system KISS, The International Symposium on Kinematic Systems In Geodesy, Geomatics and Navigation, Eisenstadt , Vienna, Austria, April 20 to April 23, 1998.

24. Sternberg H., Filter Algorithms for Optical Determination of Position and Attitude of the Mobile Mapping System Kiss, the International Workshop on Mobile Mapping Technology, Bangkok, Thailand, April 21-23, 1999

25. Tao, C. , M. A. Chapman, N. El-Sheimy, and B. Chaplin, Towards Automated Processing of Mobile Mapping Image Sequences, the International Workshop on Mobile Mapping Technology, Bangkok, Thailand, April 21-23, 1999.

26. Ron, Li, Concept of Processing Multiplatform and Multisensor Data, the International Workshop on Mobile Mapping Technology, Bangkok, Thailand, April 21-23, 1999.

27. Retscher, G., Modifications and adaptations of an on-line rail-track evaluation concept, The International Symposium on Kinematic Systems In Geodesy, Geomatics and Navigation, Eisenstadt , Vienna, Austria, April 20 to April 23, 1998.

28. Retscher, Guenther and Heribert Kahmen Precise 3-D Navigation of Building Machine Platforms, the International Workshop on Mobile Mapping Technology, Bangkok, Thailand, April 21-23, 1999.

29. Reid, D.B. and E. Lithopoulos (1998), High Precision Pointing System for Airborne Sensors. Proc. IEEE PLANS Symposium, Palm Springs, USA, April 20-23, 1998, 303-308.

FIG-C5: WG-5.31 ^{2}Robotized Integrated Positioning Systems^{2}

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Final Report

WG-5.31 was created by Prof. Jean-Marie Becker (President C5) and Dr. Naser El-Sheimy (Chair WG-5.3) in 1998 to survey and report on the evolution of Positioning and guidance of engines in real-time including the specific geodetic support needed to implement and apply these systems.
During the past four year period state-of-the-art and progress of R&D in science and industry has been monitored and filed to provide a primary data base containing internet links and references (Interim report, March 1999). An updated report has been presented lately at the occasion of the 3rd Mobile Mapping Conference in Cairo, January 2001 by the chairman.

Guidance systems for construction machines as a rule are developed jointly by specific providers of geodetic instruments and of construction machinery, often supported by regional universities or consultants offering special task knowledge and software packages. The party of sensor suppliers recently diminished, since a series of company mergers has taken place. The global players left, Leica-Magnavox-LaserAlignment, Trimble-SpectraPrecision-Zeiss, Thales-Magellan-Ashtech-MLR etc., are co-operating each with different machine suppliers to preserve patents (e.g. Leica/Gomaco, Trimble/Caterpillar). The immense concurrence situation represents the reason for very scarce detail information on any of the systems. The same holds for the few minor, but nevertheless successful rivals, like e.g. PPS or Genesys.

In outdoor environment APS and laser systems compete with GPS, indoors is still a stronghold for APS and lasers although some GPS-like systems are already in test. The main advantage of APS is height accuracy, that of GPS to work with several independent rovers.

Towards the end of 2001 we can state that guidance systems for earthmoving machines are standard and those for macadam and concrete laying are just gaining professional acceptance. What we may see in future could be the transit from guidance to automatic steering. While at present only certain tools of the machine are automatically steered, the engine’s movement itself is performed by an operator, who profits from a visual guidance support. To shift his duty to an electronic expert system will become the next target: machine control!

In tunneling another trend seems to be detectable: Although APS guidance has gained high reputation meanwhile, electronic laser systems are on their way to keep up; the specific advantage of being applicable to small diameters and of providing roll, pitch and yaw (!) even during drilling stops could be the cause. Besides, first fiber optic INS and also northfinders with mechanical gyros undertake their mission. In microtunneling most remarkable systems based on LED-targets and digital image processing are appearing.

Concerning indoor systems to guide small robots for overhead drilling or fixing purposes, no evidence of industrial developments were found. In spite of this, some successful efforts of university departments and smaller enterprises partnerships showed up. It is our belief that indoor positioning will soon become an immense field of attraction!