The future of GNSS integrated systems

Dorota A. Grejner-Brzezinska, Professor and Chair
Department of Civil, Environmental and Geodetic Engineering
President, International Association of Geodesy (IAG) Commission 4
Positioning and Applications
e-mail: dbrzezinska@osu.edu
<table>
<thead>
<tr>
<th>Topic</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNT: positioning, navigation and timing</td>
<td>- PNT and its importance</td>
</tr>
<tr>
<td></td>
<td>- Need for augmentation in GNSS-challenged environments</td>
</tr>
<tr>
<td></td>
<td>- PNT: example applications and scenarios</td>
</tr>
<tr>
<td></td>
<td>- Growing application market</td>
</tr>
<tr>
<td>Paradigm shift in navigation and sensor integration</td>
<td></td>
</tr>
<tr>
<td>Platforms and sensors</td>
<td></td>
</tr>
<tr>
<td>Navigation infrastructure</td>
<td></td>
</tr>
<tr>
<td><strong>Goal</strong>: ubiquitous navigation</td>
<td></td>
</tr>
<tr>
<td>PNT: challenges and opportunities</td>
<td></td>
</tr>
<tr>
<td>Summary and conclusions</td>
<td></td>
</tr>
<tr>
<td>SNAP’s fit to the evolving PNT landscape</td>
<td></td>
</tr>
</tbody>
</table>
What is PNT and why it is so important?

✓ **PNT** stands for *positioning, navigation, and timing*

✓ Space-based PNT refers to the capabilities enabled by:

  ❖ **Global Navigation Satellite Systems (GNSS)**
    - Global Positioning System (GPS) – US
    - Galileo – Europe
    - BeiDou/COMPASS – China
    - QZSS – Japan (regional coverage)
    - IRNSS – India (regional coverage)

  ❖ **Ground and space-based augmentation systems** – GBAS and SBAS
    - LAAS, JPALS, various DGPS Services
    - WASS, EGNOS, GAGAN, MSAS, etc.
Collectively, the space-based PNT capabilities provide position, velocity, and timing information:
- To unlimited number of users around the world, and
- Allow every user to operate in the same reference system and timing standard.

In recent years, PNT information has become increasingly critical to the security, safety, prosperity, and overall quality of life of people around the world.

As a result, space-based PNT is now widely recognized as an essential element of the global information infrastructure (National Research Council, 2010; National Academies Report on GNSS, 2012).
Example scenarios and applications of modern PNT
Global PNT plus proliferation of wireless technologies, mobile computing devices and mobile Internet have fostered a new growing interest in *location-aware systems and services*

- Personal/pedestrian navigation (PN), people, animal, asset tracking
- Emergency response/rescue operations: first responders and fire-fighters
- Fast detection of catastrophic events, e.g., tsunamis
- UAS navigation for mapping, surveillance, emergency response, etc.
- Real-time mapping and remote sensing
- Location based services – very fast growing market!
- Intelligent Transportation Systems (ITS)
- Precision farming
- Atmospheric studies, weather/climate monitoring (GNSS remote sensing)
- Leisure and professional sports
- Medicine and law enforcement, etc….
High accuracy and reliable PNT information essential for:

- Lane tracking
- Car following
- Intersections, circular intersections
- Passing
- Obstacle avoidance
- Parking
- Dynamic route planning
Integrated positioning systems for vehicle networks

- Vehicle-2-vehicle and vehicle-2-infrastructure cooperation
  - Vehicle System: sensor networks – GNSS, IMU, optical and ultrasonic sensors, LiDAR, Radar, cooperative vehicle infrastructure, communication system, etc.
  - Central System: communication with Service Center
  - Roadside System

- Collision avoidance
- Autonomous navigation
- Location-based services, etc.

Source: http://www.cvisproject.org/
PNT role in fast detection of catastrophic events: tsunami early warning system

Courtesy: GFZ Potsdam
Concept of the “farm of the future” enabled by PNT and other geospatial technologies and infrastructure

- Precise PNT anywhere in the world at all times for automated and autonomous farm machinery navigation and precision seed, water and chemicals application
- Soil moisture: monitored by remote sensing and GNSS integrated to GIS
- Local GNSS networks improve weather forecasting
- Accurate terrain, elevation and land cover information integrated with GIS will enable complex crop management
Direct Exterior Orientation

...Because sometimes it’s important to know how the platform is oriented
More application scenarios – new markets
Platforms and sensors

- Spaceborne
  - Fixed wing
  - Helicopter
  - UAV/UAS

- Airborne
  - Fixed wing
  - Helicopter
  - UAV/UAS

- Land-based
  - Vehicle
  - Autonomous
  - Pushcart
  - Man-portable

- Sea- and sub-water based
  - Ship
  - Underwater

- Navigation sensors
- Passive imaging sensors
- Active imaging sensors
- LiDAR
- SAR

GPS
IMU
Barometer/pressure sensors
Magnetometer/compass/inclinometer
Odometer/step
UWB/PL/WiFi/RFID/etc.
✓ Assuring accurate and global PNT with continuous coverage is a challenge
✓ How do we go about it?
Need for GNSS augmentation

![Diagram showing GNSS coverage gaps. The diagram illustrates the need for GNSS augmentation, particularly in areas with high-sensitivity GPS requirements, such as urban and urban/indoors environments. The diagram includes labels for space, ground level, urban/indoors, rural/open, navigation gaps, and high-sensitivity GPS.]
Paradigm shift in navigation sensor integration concept

<table>
<thead>
<tr>
<th>Single sensor</th>
<th>Conventional sensor integration</th>
<th>Integrated sensor systems</th>
<th>Sensor network of integrated sensor systems; includes unconventional sensors</th>
</tr>
</thead>
</table>

Conventional → Increasingly unconventional
Cooperative navigation: relevant to UAVs, emergency crews, dismounted soldiers, etc.

- Emergency crew, dismounted soldiers, UAVs equipped with surveillance sensors
- All platforms have ranging capability via communication ports
- Ranging connectivity allows for better and more robust PNT of a network of users in GPS-challenged environments
Collision avoidance (active and passive solutions)
Positioning Sensor Fusion
- Clear synergy between GNSS and inertial navigation system (INS)
- Focus has been on ‘bridging’ GNSS to provide continuity
- Customized blend of sensors for particular scenarios

A Changed Navigation Philosophy
- Consider INS as the primary navigation sensor
- Focus on bounding the INS error growth
- Flexible and adaptive blend with other sensors
  - includes unconventional sensors, not designed for navigation
    - *Plug and Play* concept

Research Challenges
- Flexible software architecture
- Adaptive data filtering/fusion
- Stochastic transition between different hybridizations
- Intelligent algorithms (e.g., machine learning)
**Infrastructure**

**Dedicated Infrastructure**
- RFID or proximity devices
- Ultra Wide Band (UWB)
- Static (building) or mobile (e.g., fire trucks)
- Airports, rail stations, shopping malls, universities
- Permanently tracking GNSS networks, DGPS services, etc.

**Ad hoc Infrastructure**
- WiFi access points
- Signals of opportunity (e.g., TV)
- Images, building blueprints

**No Infrastructure**
- No existing infrastructure or destroyed
- Only using sensors carried by the user
- Autonomous or collaborative navigation
Consequence of

- Paradigm shift in navigation philosophy
- Advances in imaging technology
- Increased computing power

Trends

- Static $\rightarrow$ dynamic (4D)
- Post-processing $\rightarrow$ real-time
- Increasing share of active imaging
- Big data
  - Data analytics algorithms and methods required
- Data $\rightarrow$ information (support decision making)
Goal: ubiquitous positioning

Multi-sensor, low-cost and robust positioning
- Based on single or multiple users
- Different types of platforms and sensors
- Autonomous or cooperative navigation

Seamless transition
- Different sensors
- Different platforms
- Different algorithms, when transitioning between different environments
- Plug-and-play concept

Continuous positioning across all environments
- Open areas, partially obstructed, indoor
Ubiquitous positioning

- GNSS
- Dead-reckoning sensors
- Terrestrial radio navigation
- Feature-matching sensors
- Communications
- Mapping

Courtesy of Profs. Paul Groves, UCL and Terry Moore, U of Nottingham
New technology

- More GNSS satellites
- More GNSS signals
- Communications
  - WiFi / RFID
  - UWB, Sparse Band
  - Digital broadcasting
- Pseudolites, LocataLites
- Smaller, cheaper inertial sensors
- Digital mapping (outdoor & indoor)
- More processing power
- Miniaturization, portability
- **Drives new applications**

New applications

- Seamless indoor-outdoor personal navigation
- Intelligent Transportation Systems
- Precision farming
- Rail signalling & control
- Precision aircraft landing
- Ships in harbours
- Location-dependent billing
- Virtual security fences
- Tracking people/animals/assets
- **Creates new challenges**

Courtesy of Profs. Paul Groves, UCL and Terry Moore, U of Nottingham
What user expects

- Navigation must be done in the background
- It serves the purpose and it is not the objective by itself, but it must be accurate, reliable and continuous (challenge!)
- Affordable, miniaturized/portable sensors, conventional and increasingly - unconventional
- We are almost there…
  - Smartphones 😊
  - …
Typical smartphone – needs better exploitation of its sensors
The future of LBS?

- GPS
- Wi-Fi
- 3G/GPRS
- 3-axis accelerometer
- 3-axis gyro
- 3-axis magnetometer
- Microphone
- Ambient light sensor
- Bluetooth
- Proximity sensor
- FM radio
- Camera
In summary

- Economic recession affected PNT market, but it’s changing dramatically, with new markets, devices and regions offering substantial growth.
- Emergence of real time data analysis brings new opportunities.
- Application base is rapidly growing, e.g., LBS, ITS, precision farming, indoor navigation, asset tracking, banking, etc.
- Corresponding technological developments.
- New applications create technological challenges, and these, in turn, fuel new applications.
- *The future is digitally influenced*... (Susan Wojcicki, CEO, YouTube, formerly Google)
  - Imaging sensors are rapidly advancing, are affordable and ubiquitous.
  - Motivated by environmental movement and global awareness.
- No single sensor to provide required level of accuracy, continuity and portability of PNT – *integrated systems are the future*.
Some challenges…and opportunities

- Emerging GNSS constellations bring opportunities, but also difficult design choices
- Software development will become essential
- Real-Time data aggregation and analytics will become vital
- Threats, such as LightSquared, mergers and acquisitions
- Cellular connectivity – will become essential

- Consumer equipment and new government initiatives will open new markets
- LBS – the primary driver!
- Global GNSS market growth at a CAGR of 20.98% over the period 2012-2016
- Global installed base of GNSS devices of ~ 2 billion units is predicted to grow almost four-fold to 7 billion – almost one GNSS receiver for every person on the planet by 2022 (GNSS Market Report 2013, GS)
Location-based services, or LBS, present some of the hottest opportunities in mobile commerce for both businesses and mobile operators.
Projected LBS services revenue by region (2011-2017)

Global LBS Revenue — by Region

Source: ABI Research, 2012
Increasing interest in PNT-related job market 😊

My Little Pony… … has been replaced by “My Little Drony”

Generation Z is actively growing their expertise in PNT: Saskia Uijt de Haag working on the new generation of drones 😊
Dog walkers are losing their jobs to drones! 😊
SNAP’s role

✓ One of the most prominent PNT research labs in the Asia-Pacific region, well recognized world-wide
  ❖ Strong presence at ION meetings
  ❖ 31 winners of the ION student competition since 1988
  ❖ Strong industry connection (Locata, Leica, etc.)
  ❖ Leadership in IAG and ISPRS – prominent professional organizations

✓ New interdisciplinary research opportunities in the current affiliation with the Department of Civil & Env. Engineering
  ❖ Water and climate studies, transportation networks, highway safety and collision avoidance, ITS, infrastructure monitoring, smart cities, landslide and deformation monitoring, flood control, landfill clean-up, etc.

✓ SNAP’s expertise in PNT research is a full continuum from geodesy to surveying to navigation, including technology component
  ❖ Geospatial background provides a unique “big picture” perspective
  ❖ Signal processing/EE component provides technology/industry connection

✓ Asia-Pacific is the fastest growing PNT market → new constellations (Beidou, QZSS, IRNSS, etc.), massive consumer market, government initiatives in precision PNT, etc.