SCIENCE & TECHNOLOGY RESEARCH INSTITUTE
FOR DEFENCE
MINISTRY OF DEFENCE
STRIDE

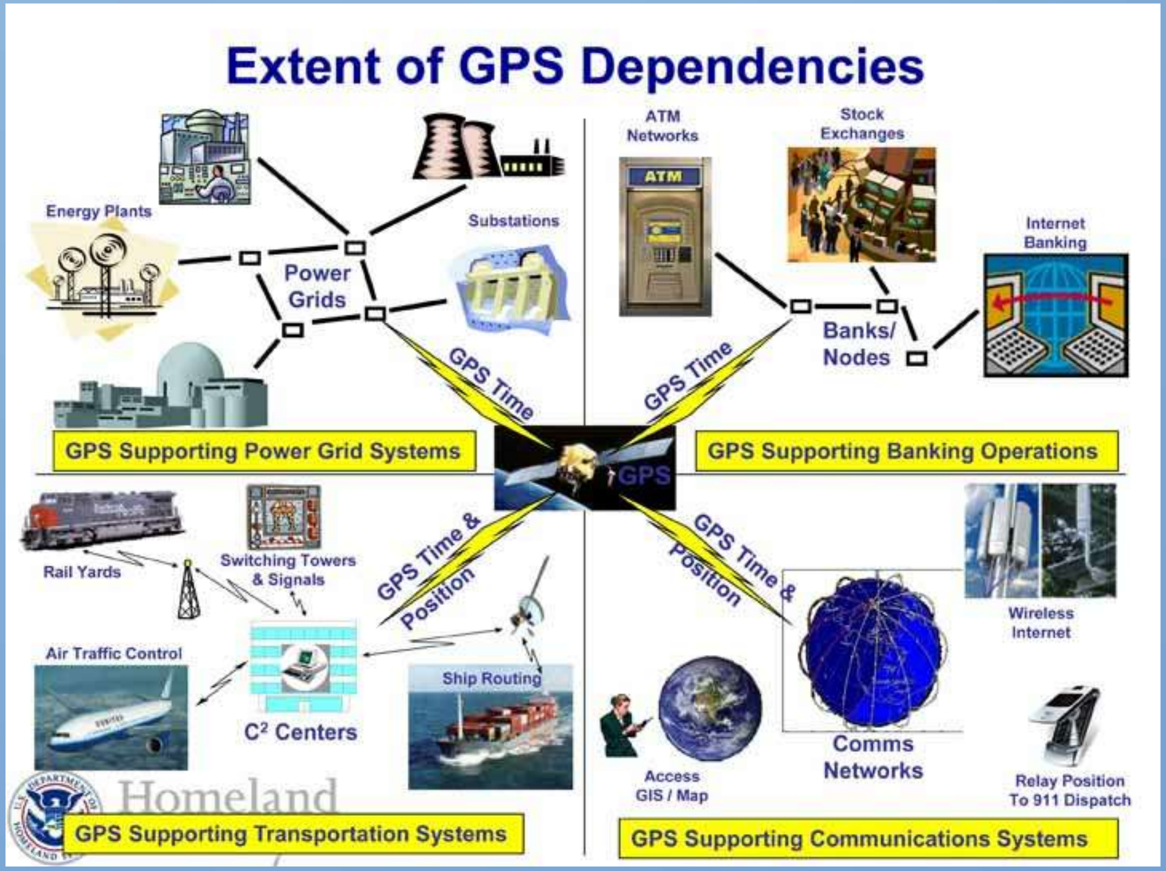
Evaluating the Effect of Global Positioning System (GPS) Antenna Orientation on GPS Performance

STRIDE

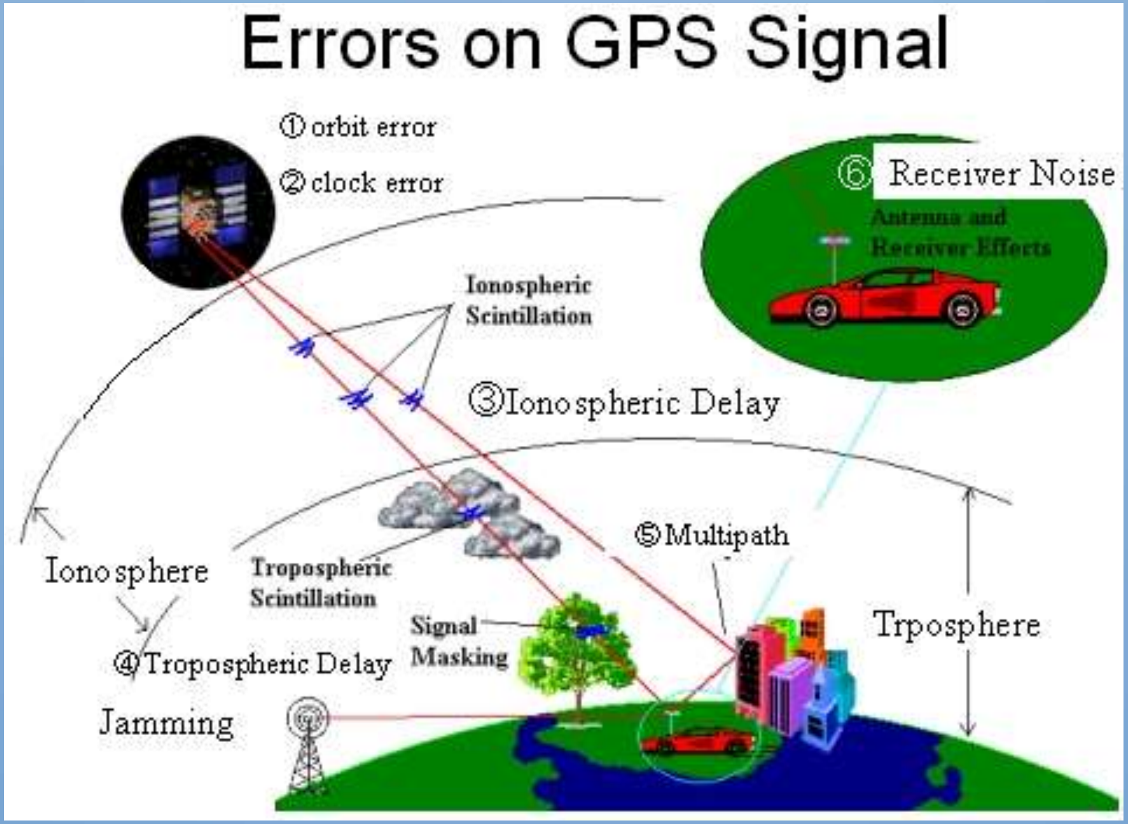
Introduction

Increasing use for PNT applications:

- ♦Positioning
- ♦Navigation
- ♦Timing



GNSS Vulnerabilities



Source: IranMap.com

STRIDE

GNSS Receiver Evaluation

- Many designers are working on improving characteristics of GNSS receivers, such as:
  - Lower power consumption
  - Tracking of weak satellite signals
  - Acquisition time
  - Positioning and timing accuracy
  - Radio frequency interference (RFI) interoperability
- Many developers and users still struggle to identify suitable standard tests to objectively verify and evaluate the functionality and performance of GNSS receivers.

STRIDE

GNSS Receiver Evaluation

Field Evaluation

- Employs live GNSS signals.
- Should be conducted in open area with clear view of the sky.
- Tests scenarios are uncontrollable by users and not repeatable.

GNSS Simulation

- Employs simulated GNSS signals.
- Should be conducted in a RF enclosure (e.g. anechoic chamber).
- Test scenarios are user controllable and repeatable.

STRIDE

Research Theme

Title: Simulation and Modelling of Global Navigation Satellite System (GNSS) Vulnerabilities

Research Objectives:

- GNSS simulation will be used to model the effect of the following vulnerabilities on GNSS receiver performances:
  - Radio frequency interference (RFI)
  - Spoofing
  - Ionospheric and tropospheric delays
  - LOS blockage and multipath errors

STRIDE

R&D Projects Conducted

Num.	Project Title	Status	Duration
1	Evaluation of the Effect of Radio Frequency Interference (RFI) on Global Positioning System (GPS) Signals	Internal	November 2009 – June 2010
2	Evaluation of the Effect of Radio Frequency Interference (RFI) on Global Positioning System (GPS) Signals via GPS Simulation	RMK10	January 2011 – May 2012
3	Evaluation of the Effect of Multipath on Global Positioning System (GPS) Signals via GPS Simulation	Internal	January 2013 – January 2014
4	Evaluation of the Effect of Global Positioning System (GPS) Satellite Clock Error via GPS Simulation	Internal	April – September 2014
5	Evaluation of Trade-Off Between Global Positioning System (GPS) Accuracy and Power Saving from Reduction of Number of GPS Receiver Channels	Internal	November 2014 – March 2015
6	Evaluation of the Accuracy of Global Positioning System (GPS) Speed Measurement via GPS Simulation	Internal	May – August 2015
7	Evaluation of the Effect of Global Positioning System (GPS) Antenna Orientation on GPS Performance	Internal	October 2015 – August 2016
8	Evaluation of Global Positioning System (GPS) Adjacent Band Compatibility via GPS Simulation	Internal	October 2016 – Current
9	Simulation and Modelling of Global Navigation Satellite System (GNSS) Vulnerabilities	Proposed for RMK11	January 2018 – December 2019

Presentation Outline

- Review of activities conducted on vulnerabilities of GPS to:
  - Radio frequency interference (RFI)
  - Simplistic spoofing
  - Static multipath
  - GPS satellite clock error
  - Power consumption
  - Speed measurement
  - Antenna orientation

- Future research direction:
  - Intermediate spoofing
  - Dynamic multipath
  - Ionospheric and troposheric delays
  - Extension to other GNSS systems; GLONASS, BeiDou and Galileo

STRIDE

GNSS Antenna Orientation

- Antennas are a critical part of any GNSS receiver design and their importance cannot be stated highly enough.
- GNSS signals are extremely weak and present unique demands on the antenna.
- Even the best receiver cannot bring back what has been lost due to a poor antenna design.
- The choice and implementation of the antenna plays a significant role in GNSS performance

STRIDE

GNSS Antenna Orientation

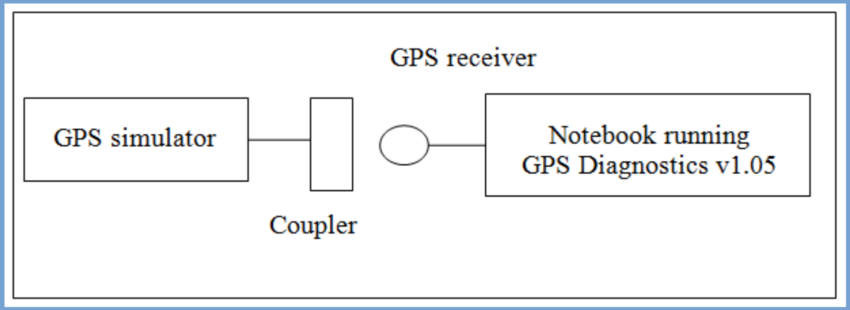
- Ideally, a GNSS antenna should have an isotropic response pattern that is independent of its orientation or direction of arrival of GNSS signals.
- However, there are no ideal antennas in the real world and real antennas do not have an isotropic response pattern.
- This means that the same signal received at various antenna orientations can result in stronger or weaker signals being presented to the receiver front end.
- To this end, the evaluation of the effect of GNSS antenna orientation on GNSS performance has received significant attention

Objective

- This study is aimed at evaluating the effect of GPS antenna orientation for three Garmin GPS receivers that use built-in quad helix antennas;
  - GPSmap 60CSx
  - GPSmap 62Cs
  - Oregon 550

STRIDE

Methodology



The following assumptions are made for the tests conducted:

- No ionospheric or troposheric delays
- No clock and ephemeris error
- No unintended multipath fading or obstructions
- No interference signals

Test locations:

- N 2° 58' E 101° 48' (Kajang, Selangor, Malaysia)
- N 39° 45' W 105° 00' (Denver, Colorado, USA)
- S 16° 55' E 145° 46' (Cairns, Queensland, Australia)
- S 51° 37' W 69° 12' (Rio Gallegos, Argentina)

UTC times:

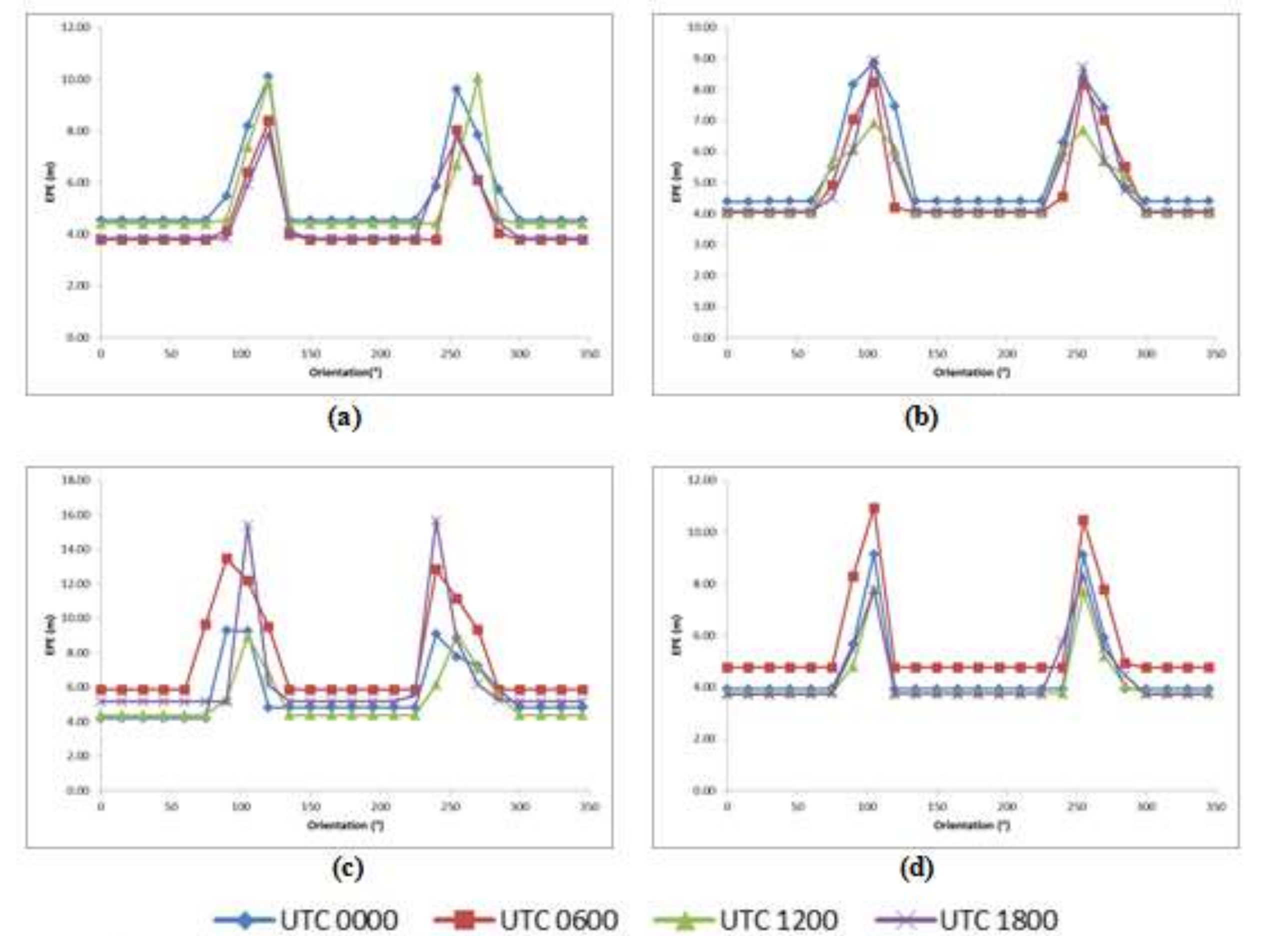
- 0000
- 0300
- 0600
- 0900

Readings are taken for GPS antenna orientations of 0 to 345°, at increments of 15°. For each reading, values of estimate probable error (EPE) are recorded for a period of 15 min.

Results & Discussion

STRIDE

GPSmap 60CSx

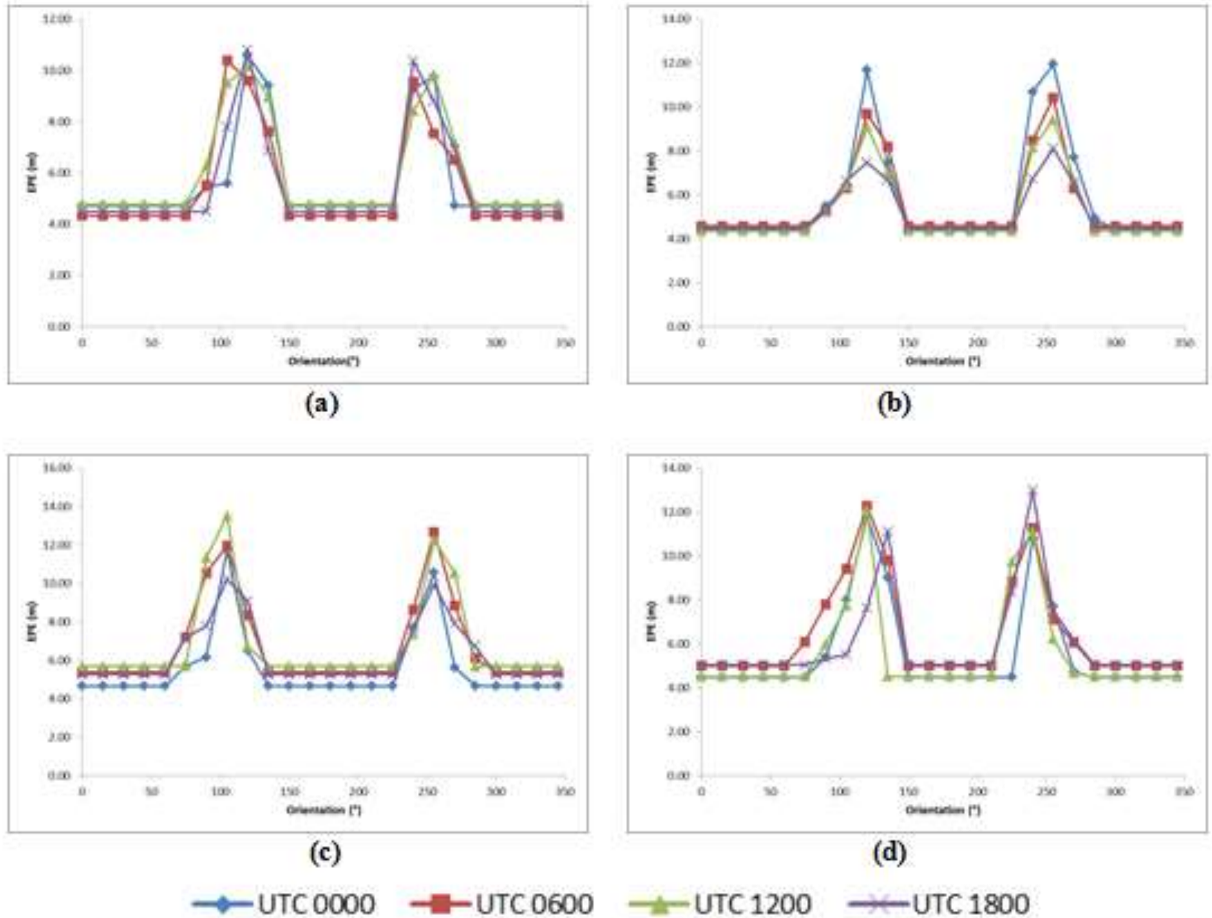


Recorded EPE values for the GPSmap 60CSx receiver: (a) Kajang (b) Denver (c) Cairns (d) Rio Gallegos.

Results & Discussion

STRIDE

GPSmap 62Cs

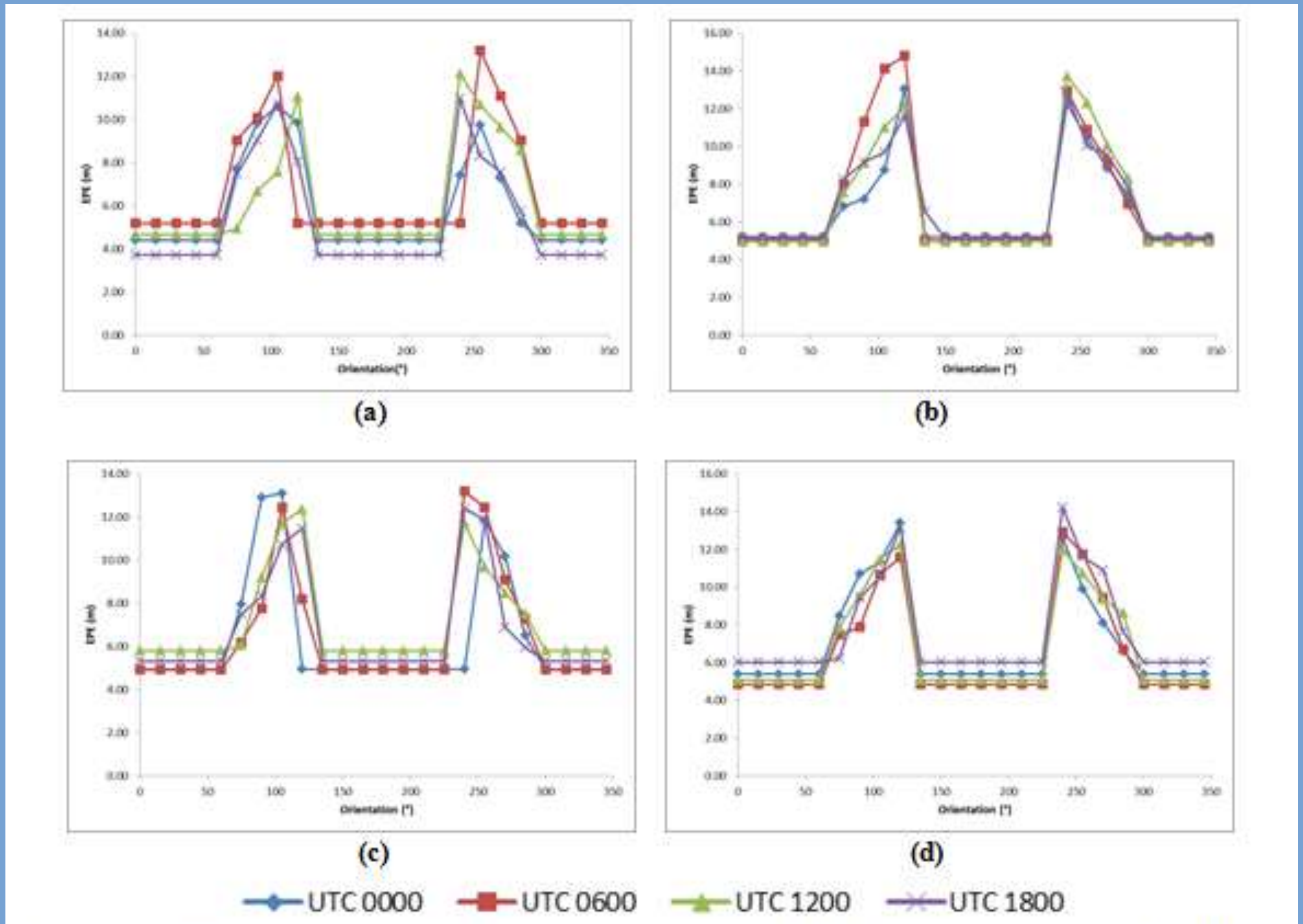


Recorded EPE values for the GPSmap 62Cs receiver: (a) Kajang (b) Denver (c) Cairns (d) Rio Gallegos.

STRIDE

Results & Discussion

Oregon 550

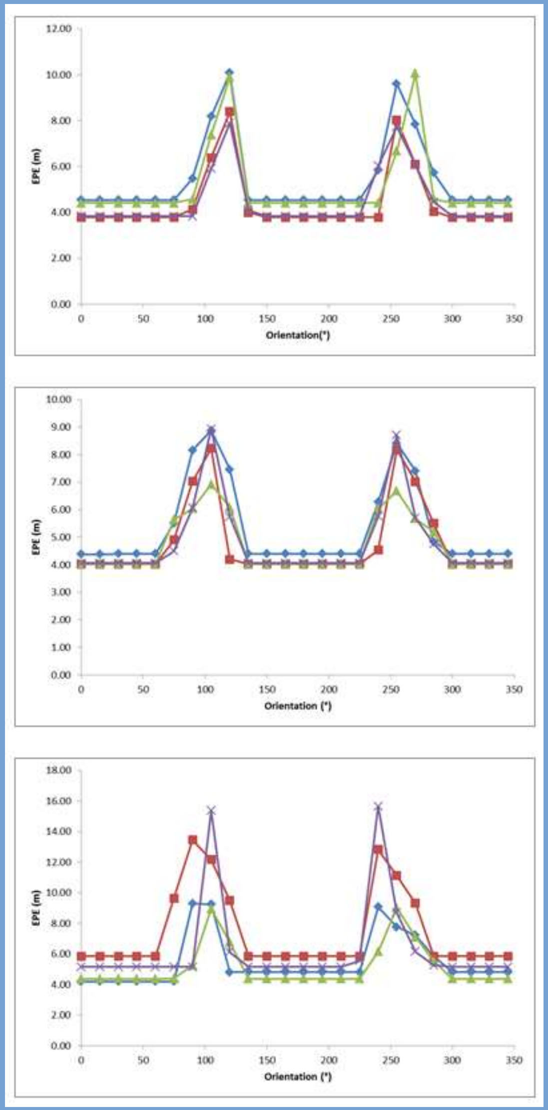


Recorded EPE values for the Oregon 550 receiver: (a) Kajang (b) Denver (c) Cairns (d) Rio Gallegos.

STRIDE

Results & Discussion

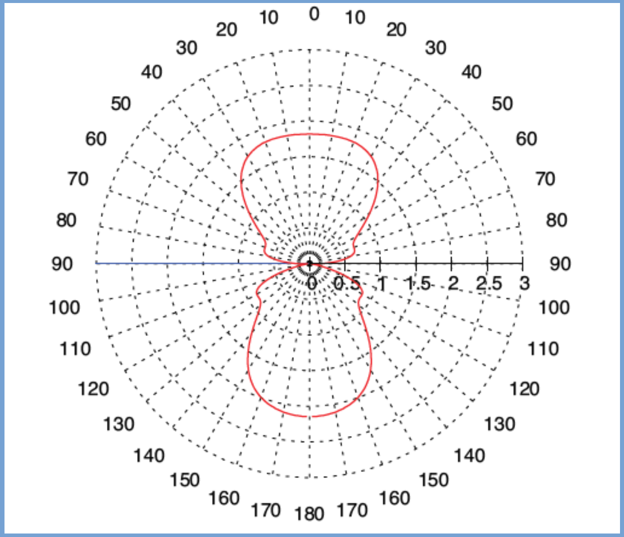
- It is found that there is degradation of accuracy for antenna orientations of 75 to 120° and 240 to 285°.
- This indicates that for these orientations, the antenna gain is lower, resulting in reduced carrier-to-noise density (C/N_0) levels for GPS satellites tracked by the receivers, which is the ratio of received GPS signal power level to noise density.
- Lower C/N0 levels result in increased data bit error rate when extracting navigation data from GPS signals, and hence, increased carrier and code tracking loop jitter.
- This, in turn, results in more noisy range measurements and thus, less precise positioning.
- For the remaining orientations, the performance remains constant.



STRIDE

Results & Discussion

- These results indicate that the quad helix antennas are operating in endfire and backfire modes simultaneously.
- While this type of design has smaller antenna gain than quad helix antennas that use only endfire or backfire modes, it allows for a more isotropic antenna performance.



Example of the radiation pattern of a quad helix antenna operating in endfire and backfire modes simultaneously

STRIDE

Conclusion

- It was found that there was degradation of accuracy for orientations of 75 to 120° and 240 to 285°.
- For the remaining orientations, the accuracy remained constant. This indicates that the quad helix antennas are operating in endfire and backfire modes simultaneously.
- While this type of design has smaller antenna gain than quad helix antennas that use only endfire or backfire modes, it allows for a more isotropic antenna performance.
- This study will be extended to evaluate the performance of antennas of a wider range of GPS receivers.

STRIDE

Scope for Future Work

- The proposed scope for future work includes the extension of this study to perform the simulation and modelling of:
  - Intermediate spoofing
  - Dynamic multipath
  - Ionospheric and troposheric delays
  - Extension to other GNSS systems; GLONASS, BeiDou and Galileo

STRIDE

GPS Functional Tests

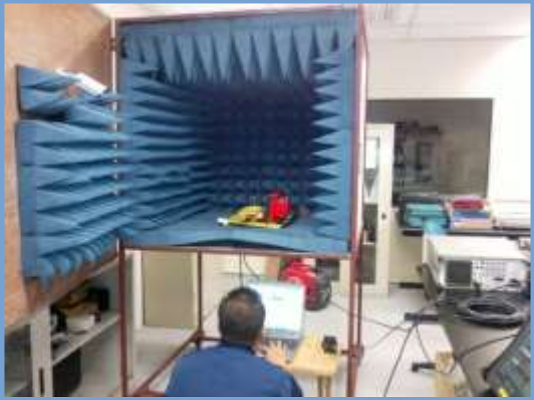
Pendulum Instruments GPS-12R

Magellan Z-Max

Trimble Geoexplorer 6000 GeoXH, Nomad 900G and Juno SB

Topcon Hiper GA

Trimble R8



ProMark 200

STRIDE

Research Collaborations

- Effect of Radio Frequency Interference (RFI) on Global Positioning System (GPS) Static Observations (2012)
  - Collaboration with the Faculty of Architecture, Planning and Surveying (FSPU), Universiti Teknologi MARA (UiTM)
  - Project Co-Leaders:
    - Assoc. Prof. Sr. Dr. Azman Mohd Suldi
    - Mr. Ahmad Norhisyam Idris

- Power Efficient Global Positioning System (GPS) Receiver Design (2014)
  - Collaboration with the Department of Computer and Communication Systems Engineering, Universiti Putra Malaysia (UPM)
  - Project Co-Leaders:
    - Dr. Fakhrul Zaman Rokhani
    - Mr. Fawaz Mohamed Jumaah

THANK YOU