Practical 3

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1. Observations and Calculations

1.1 Stand-alone GPS (positioned using pseudoranges in stand-alone mode)

Point	Northing	Easting
0m	818705.746	836529.429
10m	818705.299	836539.417
Calculation Distance:	9.997997449503625	-
Error:	-0.0020025504963747665	-

1.2 DGPS (positioned using pseudoranges in differential mode)

Point	Northing	Easting
0m	818706.328	836529.265
10m	818705.596	836539.340
Calculation Distance:	10.101556761163256	-
Error:	0.10155676116325552	-

1.3 RTK GPS (positioned using carrier phase in kinematic mode)

Point	Northing	Easting
0m	818705.776	836529.432
10m	818705.318	836539.409
Calculation Distance:	9.987506846009843	-
Error:	-0.012493153990156713	-

1.4 RTK GNSS (positioned using carrier phase in kinematic mode)

Point	Northing	Easting
0m	818705.786	836529.439
10m	818705.322	836539.410
Calculation Distance:	9.981790270303003	-
Error:	-0.018209729696996746	-

1.5 Post-processing GNSS PPP (positioned using carrier phase in static mode)

- In the local coordinate system, the coordinates of the two points are as follows:

Point	UTM Northing	UTM Easting
0m	2469547.553	209404.775
10m	2469538.031	209401.867
Calculation Distance:	9.956151264304165	-
Error:	-0.04384873569583547	-

- In the 3D space, the coordinates of the two points are as follows:

Point	X	Y	Z
0	-2418120.5654	5385741.1718	2405920.7909
1	-2418121.5392	5385736.6821	2405929.6164
Calculation Distance:	9.949630283712642	-	
Error:	-0.0503697162873582	-	

2. Account for the differences between the GNSS positioning techniques

Technique	Theory
Stand-alone GPS	Stand-alone GPS positioning uses pseudoranges for positioning, without additional correction information. It is limited by factors such as atmospheric errors, satellite orbits, and clock errors, so its accuracy is relatively low.
DGPS	Differential GPS can reduce errors in stand-alone GPS by receiving correction information sent by reference stations, such as ionospheric and tropospheric errors.
RTK GPS	RTK GPS uses carrier phase measurements to improve accuracy. It requires real-time transmission of carrier phase information between the base station and the rover.
RTK GNSS	RTK GNSS is similar to RTK GPS, but it can use signals from multiple satellite systems, such as GPS, GLONASS, Galileo, etc., to provide more available satellites for improved accuracy and availability.
Post-processing GNSS PPP	PPP does not require a reference station, but uses precise orbit and clock correction information to achieve decimeter to centimeter-level positioning accuracy. In this experiment, we performed post-processing using precise orbit and clock correction data after the observation (the procise reference data udated about 10.22).

3. Analyse the differences based on the theory of the five positioning techniques

Technique	Distance (m)	Error (m)
Stand-alone GPS	9.997997449503625	**-0.0020025504963747665**
DGPS	10.101556761163256	**0.10155676116325552**
RTK GPS	9.987506846009843	-0.012493153990156713
RTK GNSS	9.981790270303003	-0.018209729696996746
Post-processing GNSS PPP	9.956151264304165	-0.04384873569583547

If we consider the true value is 10m :

- Stand-alone GPS(about 0.002) & DGPS(about 0.1) : The measurement result of Stand-alone GPS is the closest to the true value, while the error of DGPS is the largest among all measurements.
- RTK GPS & RTK GNSS(about 0.01 - 0.02) : The measurement results of RTK GPS and RTK GNSS are similar, with the error of RTK GNSS slightly larger than that of RTK GPS.
- Post-processing GNSS PPP(about 0.04) : The error is larger than RTK.

Here, some anomalies have occurred, where some methods that were originally considered to be high-precision have larger errors, indicating that the accuracy of GPS positioning technology is affected by multiple factors.

Technique	Analysis
Stand-alone GPS	The error of Stand-alone GPS positioning is **-0.002 meters**, which is close to the ideal value. This small error may be due to good signal reception conditions, and the error has not been significantly amplified. I checked the satellite distribution during the measurement, and the satellite distribution conditions were good at that time (18:10-18:20, Figue 1), while the subsequent measurement DOP gradually increased, which is also a possible influence.
DGPS	The calculated distance error of DGPS is **0.101 meters**, which is larger than that of Stand-alone GPS. Although differential technology usually improves accuracy, the actual effect is limited by the distance between the base station and the rover, as well as signal propagation paths and other conditions.
RTK GPS	The error of RTK GPS is **-0.012 meters**, which is relatively accurate. This is because carrier phase measurements have high accuracy and can effectively reduce common error sources such as satellite clock errors and ionospheric errors.
RTK GNSS	The error of RTK GNSS is **-0.018 meters**, slightly larger than RTK GPS. This may be related to satellite combinations, signal environments, and multipath effects during observation. Although GNSS uses multiple satellite systems, the impact of signal propagation environments cannot be ignored. At the same time, the satellite DOP at this time (19:00, Figue 2) gradually increased, which will have a certain impact.
Post-processing GNSS PPP	The error of PPP is **-0.043 meters**, slightly larger than RTK technology. This may be related to the atmospheric conditions and satellite distribution at that time. Considering that PPP requires long-term observation (15 minutes) with instruments, receiver noise errors, ionospheric errors, etc., may accumulate during this time.

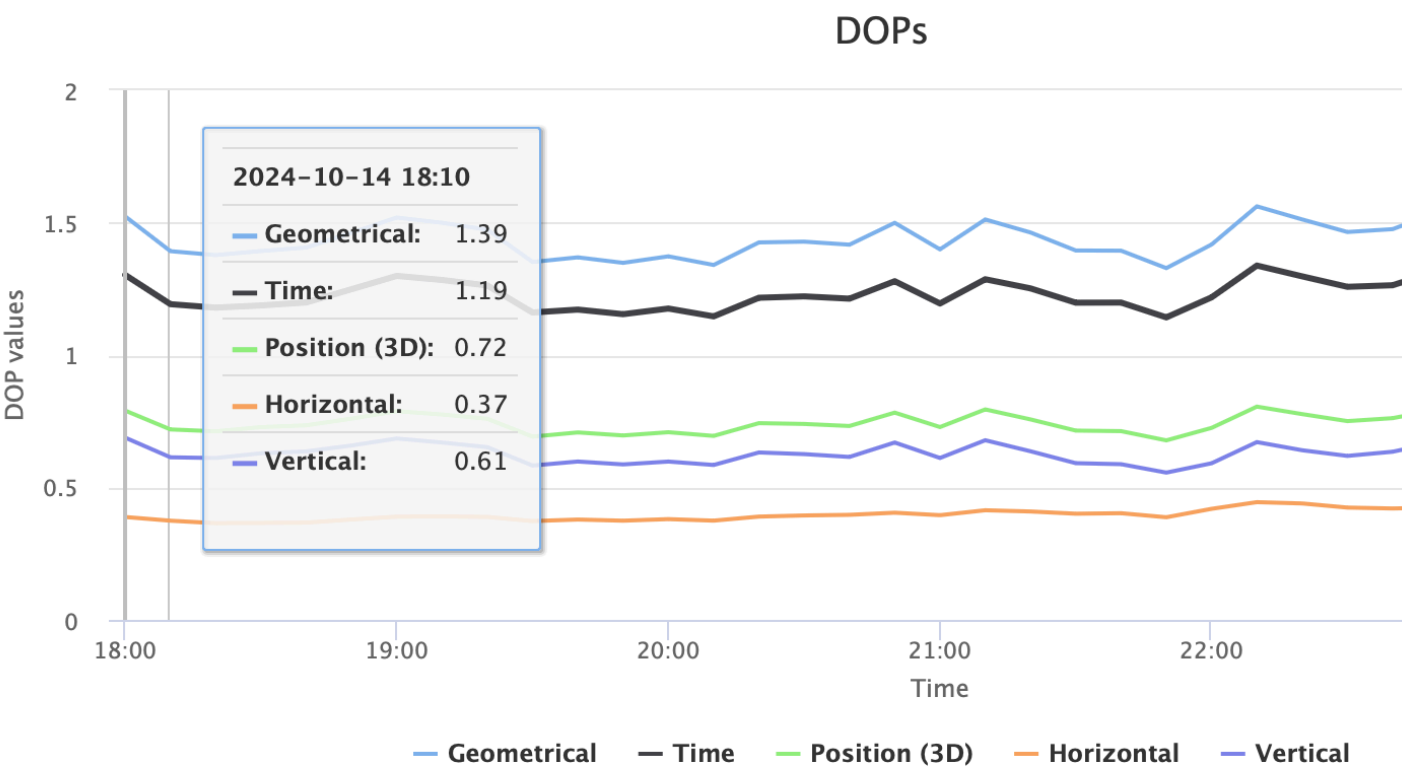

Figure 1: Satellite distribution at 18:10-18:20

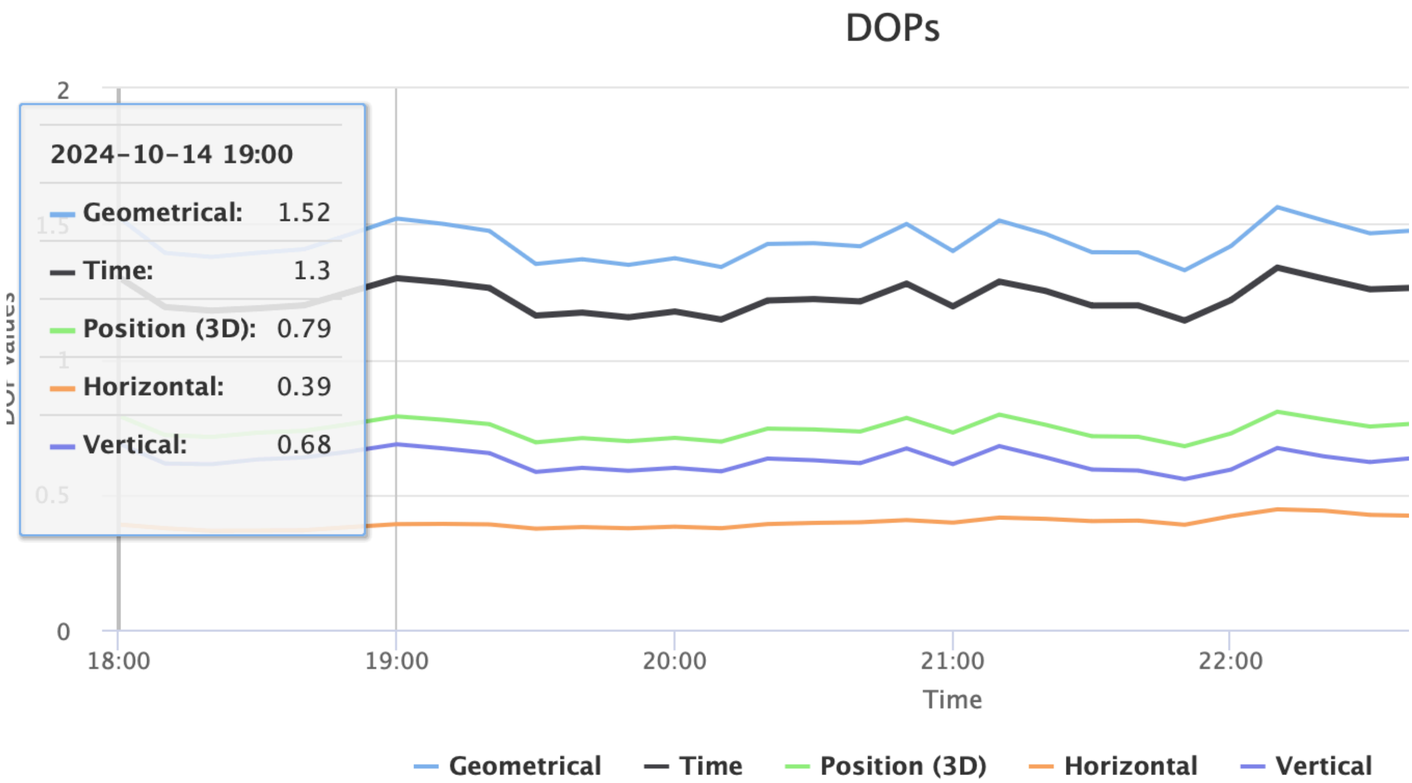

Figure 2: Satellite distribution at 19:00

> - Data Source: https://www.gnssplanning.com/
> - Date & Time: 14/10/2024 18:10-20:00
> - Location: Hong Kong (N 22° 18' 24.8727", E 114° 10' 46.1023")

Appendix

1. Code for calculating the distance:

```
import math

def calculate_distance(x1, y1, x2, y2):
    return math.sqrt((x1 - x2) ** 2 + (y1 - y2) ** 2)

# Stand-alone GPS
distance_gps = calculate_distance(818705.746, 836529.429, 818705.299, 836539.417)
error_gps = distance_gps - 10

# DGPS
distance_dgps = calculate_distance(818706.328, 836529.265, 818705.596, 836539.340)
error_dgps = distance_dgps - 10

# RTK GPS
distance_rtk_gps = calculate_distance(818705.776, 836529.432, 818705.318, 836539.409)
error_rtk_gps = distance_rtk_gps - 10

# RTK GNSS
distance_rtk_gnss = calculate_distance(818705.786, 836529.439, 818705.322, 836539.410)
error_rtk_gnss = distance_rtk_gnss - 10

# Post-processing GNSS PPP
distance_ppp = calculate_distance(2469547.553, 209404.775, 2469538.031, 209401.867)
error_ppp = distance_ppp - 10

def calculate_distance_3d(x1, y1, z1, x2, y2, z2):
    return math.sqrt((x1 - x2) ** 2 + (y1 - y2) ** 2 + (z1 - z2) ** 2)

# in one print message
print(f"Stand-alone GPS: Distance = {distance_gps}, Error = {error_gps}\n"
      f"DGPS: Distance = {distance_dgps}, Error = {error_dgps}\n"
      f"RTK GPS: Distance = {distance_rtk_gps}, Error = {error_rtk_gps}\n"
      f"RTK GNSS: Distance = {distance_rtk_gnss}, Error = {error_rtk_gnss}\n"
      f"Post-processing GNSS PPP: Distance = {distance_ppp}, Error = {error_ppp}\n"
      f"Post-processing GNSS PPP 3D: Distance = {distance_ppp_3d}, Error = {error_ppp_3d}")

# Output:
# Stand-alone GPS: Distance = 9.997997449503625, Error = -0.0020025504963747665
# DGPS: Distance = 10.101556761163256, Error = 0.10155676116325552
# RTK GPS: Distance = 9.987506846009843, Error = -0.012493153990156713
# RTK GNSS: Distance = 9.981790270303003, Error = -0.018209729696996746
# Post-processing GNSS PPP: Distance = 9.956151264304165, Error = -0.04384873569583547
# Post-processing GNSS PPP 3D: Distance = 9.949630283712642, Error = -0.0503697162873582
```

2. Original PPP Data & Calculation Result Link :
   https://github.com/pzq123456/LSGI522/tree/main/Practicals/Practical3/data

References

1. https://www.gnssplanning.com/