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Towards Smart Green Blue Infrastructure

Heading Accuracy by Dual Antenna GNSS using Differential and Real Time Kinematic Techniques Compared to Gyrocompass

Eslam Abdelsatar [(1)i], Eman Hamdan [(2)], and Ahmed Khedr [(3)]

[(1)] College of Maritime Transport and Technology, Arab Academy for Science, Technology and Maritime Transport, Abu-Qir, Alexandria, Egypt, eslam_abdelsatar@hotmail.com
[(2)] Marine engineering technology department, Arab Academy for Science, Technology and Maritime Transport, Abu-Qir, Alexandria, Egypt, eman_youssef@aast.edu
[(3)] *College of Maritime Transport and Technology, Arab Academy for Science, Technology and Maritime Transport, Abu-Qir, Alexandria, Egypt,* akhedr@aast.edu

ABSTRACT

Vessel heading is the direction in which ships are moving at any specific moment. Vessel heading is crucial for navigation as it helps in determining the vessel's course, making steering decisions, and ensuring the vessel follows a desired path. In maritime history, heading has always been a myth that needs to be figured out by all sailors at all time. In ancient times, celestial bodies were used to acquire destinations referred to true north. The accuracy of vessel heading is essential for safe and precise navigation, especially in challenging maritime conditions. Vessel heading instruments, have undergone evolution starting from lodestones as the earliest natural magnetic compass to modern-day gyrocompasses, laser gyros, and inertial systems. With the advent of satellite technology and global navigation satellite systems (GNSS) on board vessels, there has been a paradigm shift in calculating courses over ground, driven by the limitations and errors associated with magnetic compasses, such as variation and deviation in addition to the high costs of gyrocompasses. In response to the challenges posed by the drawbacks, this paper delves into two alternative techniques and systems for acquiring vessels' true heading. The first method employs real-time kinematics (RTK) with dual antennas, while the second utilizes a differential global positioning system (DGPS) with dual antennas also. This paper aims to check if these novel techniques are accounted for, to provide a reliable alternative to traditional heading acquisition from compasses. To assess the effectiveness of these new techniques, a correlation analysis was conducted comparing headings obtained from the gyrocompass with the heading from both RTK and DGPS, in both static and dynamic modes. The results revealed a remarkably strong correlation of 0.9 between the gyrocompass and both RTK and DGPS receivers, with a negligible standard deviation of ±0.1° in static and ±0.18° in dynamic. This comparative study underscores the potential of the proposed GNSS-based methods as accurate and cost-effective alternatives for acquiring vessel headings, showcasing their reliability in both static and dynamic conditions. The comparison of different heading acquisition techniques is important in determining which method provides the most accurate and reliable results in different conditions. This involves implementing redundant or complementary methods to ensure reliability in critical applications.

Keywords: Heading, Gyro, RTK heading, Differential heading, true north, Grid north.

INTRODUCTION

In prehistoric times, ancient mariners used stars in the sky to find their own location on earth besides the heading of the trip. Polaris, or north pole, was the reference direction to measure trip heading, referring to true or geographic north.

By 1300s, magnetic compasses had begun to appear across Europe and the Middle East. Most of mariners believe that Chinese introduced their magnetic compass to Arabs, who then shared this knowledge with the Europeans (Amelia Carolina Sparavigna, 2011). For many years, the magnetic compass allowed mariners to travel excessively confidently throughout the oceans and seas.

Magnetic compass point to the magnetic north, which is the direction aligned with the earth's magnetic field, and it is approximately 1,000 miles from the true geographic North pole. A magnetic compass's user can determine true north by finding the magnetic north and then correcting for variation and deviation. Variation is defined as the angle between the true (geographic) north and the direction of magnetic north caused by an earth magnetic field while, deviation is the angle between magnetic north and compass north as a result of ship magnetism (Wright and Monte, 1972).

In 18th century, the first form of gyrocompass was patented, until a usable gyrocompass was invented in 1906 in Germany. Then, after successful tests in 1908, it became widely used onboard vessels worldwide for both military and commercial purposes (Guarneri, 2014). All gyrocompasses operate on the same basic principle, but they differ in their methods of supporting the gyroscopic element (spinning wheel), beside applying the pendulosity that is required for the north-seeking property. Following this, the first experimental ring laser gyroscope was demonstrated in the United States in 1963 (Macek and Davis,1963).

After the enormous advent of satellites, especially the global positioning system (GPS) course over ground was acquired onboard ships, using vehicle component vector differentiation techniques for accurate heading. In current times, the global navigation satellite system (GNSS) is used to integrate multi-global navigational systems such as the global navigation satellite system (GLONASS), Galileo system and Beidou system, that can enhance ship position and sequentially ship heading. In hydrographic surveying, it is essential to acquire an accurate course for the vessel commencing the operation. Thus, the heading is extremely important for data certainty. Recently, new means came up to determine the direction of any vehicles towards their intended destination, referred to as the true north, such as real-time kinematics (RTK) and differential poisoning system (DGPS) heading.

This paper embarks on a comprehensive exploration of the historical trajectory of vessel heading instruments, examines the drawbacks of existing methods, and introduces these two cutting-edge techniques. Through a rigorous comparative analysis, the study assesses the correlation between headings obtained from traditional gyrocompasses and the proposed RTK and DGPS systems in both static and dynamic scenarios. The findings shed light on the efficacy of these emerging GNSS-based technologies as viable alternatives for enhancing vessel heading accuracy and navigating the maritime challenges of the 21st century.

RESEARCH METHODOLOGY

In recent years, a broad range of research studies have been focusing on the concept of cooperation across firms to enhance the efficiency and competitiveness of supply chains. The importance of cooperation has been highlighted particularly in the field of logistics and supply chain management as this is referred to as the way for firms to enhance competitiveness, improve and integrate operational processes (Christopher, [11]; Barrat, [12]; Sandberg, [13]).

The term 'cooperation' in many cases has been used interchangeably with the terms such as 'coordination' and 'collaboration' (Castaner & Oliveira, [14]) which eventually leads to confusion. In general, the concept of cooperation differs depending upon the level of integration that the involved firms can achieve. A lower level of integration has been defined as 'collaboration' or the harmonization of the business processes of firms that are mutually adjusted to attain goals successfully (Göpfert, [15]). On the other hand, cooperation is defined as '*the practice of entities or people working together with common objectives*' (Kamis *et al.,* [16]) whilst (Gulati *et al.,* [17]) defined coordination as '*the deliberate and orderly alignment or adjustment of partners*' actions to achieve jointly determined goals.

Increased competition across international supply chains has been converted into a collection of fragmented supply chains and high intensity concentration of logistics activities within limited spatial concentration (Bolumole *et al.,* [18]). Therefore, regional development is highly dependent upon the competitiveness of supply chain for economic development and regional cooperation has become a key element to strengthen logistics activities. Regional cooperation within neighbouring countries has the potential to generate several advantages from the logistics point of view and to strengthen international trade participation. With intensified cooperation in a region, there is a possibility of strengthened and more integrated supply chains that can lead to potential cost savings and increase in efficiency. This cooperation is specifically significant for those nations which do not have highly developed and productive transport networks individually (Bui & Duc, [19]).

Intra-regional logistics cooperation can lead to the creation of spatial concentration and a more integrated transport network (Van den Heuvel *et al.,* [20]) and consequent reduction of freight transport (Wagner, [21]). As defined by Porter [22], a regional cluster is a geographically proximate group of interconnected companies and associated institutions. This term further reinforces the idea that regional cooperation can only be achieved through creation of synergistic relationships among all supply chain stakeholders by aligning individual action towards a common objective (Fugate *et al*., [23]). Regional logistics clusters create opportunities to develop platforms which generate economic output. However, this is strictly dependent on the firms located within the spatial concentration (Snowdon & Stonehouse, [24]).

Van den Heuvel *et al*., [25] studied the effects of spatial concentration about land allocation policies of municipalities in the south of the Netherlands. They found that logistics companies co-located within a spatial cluster are more likely to share transport capacity and decrease CO2 emissions as compared to non-co-located logistics companies. Xiu [26] explored regional logistics cooperation on the basis of industrial clusters and suggested that the advantages of co-located industries do not come from the aggregation of firms but rather from the series of internal and external regional interactions related to the cluster. Furthermore, the effects of regional logistics clusters are influential on the logistics labor market, for knowledge sharing among participating entities (Sheffi, [27]) and also act as a catalyst for investment attractions as well as infrastructure developments (Snowdon & Stonehouse, [24]). Nevertheless, successful promotion and implementation of an intra-regional logistics coordination is a complex exercise and requires several factors to be considered.

RESEARCH DESIGN PROCEDURES

Area of study

For the purpose of comparison between different heading acquisition techniques. Inside Alexandria Western Harbor (AWH) was chosen according to the calm sea state and average weather circumstances, and it is protected by breakwater as shown in figure 1. Quay number 65 (31 10 58 N, 29 52 36 E) was used for the static data acquisition. The location was chosen carefully to avoid the effects of both multipath errors (MP) and masking angle errors in static mode. The Alexandria internal navigational channel was also chosen as the best route for dynamic mode to avoid ship traffic and wave damping.

Figure 1: Alexandria Western Harbor.

Instrumentation and initial installation

Instrumentation

1. A hydrographic surveying vessel with a 16-metre length and 5-metre width and a 1.5-metre draft was used all over the research,

2. Meridians gyro compass with true heading accuracy in static mode 0.10° secant latitude root mean square (RMS) and 0.30° secant latitude in dynamic.

3. Trimble device provides a heading accuracy that varies between 0.05° and 0.09° RMS (grid heading). There are two modes available for receiving correction: RTK and differential GPS. In addition, it is equipped with an RTK base station that contains both transmitting and receiving radio.

Software

1. Hypack software was used to integrate all instruments together. The time for the observation was registered through Hypack and synchronized with the instruments.

2. AutoCAD and Google Earth software were used for offset drawings.

3. MATLAB and Excel for statistical analysis and correlation.

Initial installation and offsets

A dual-antenna GPS/GLONASS system equipped with a receiver for DGPS heading and RTK heading, along with Meridians gyro, were effectively installed on the survey vessel. The installation process adhered to the precise instructions provided in the manual, ensuring accurate offsets, as shown in Figure2. When installing the GPS/GLONASS antenna system, the locations of the antennas, the distance between adjacent antennas, and the stability of the antenna mounts were taken into consideration according to the vessel length. Each location where an antenna is installed ought to make every effort to be free of obstructions that could have a severe impact. This is due to two different reasons. First, it prevents satellite signal interruptions and has a clearer view of the sky as a result. Second, it reduces the influence of multiple paths, which is important because multiple paths can lead to a significant number of errors. Gyro meridian was connected to the Hypack programme by throwing out a serial cable with a baud rate of 9600 and 1 hz; GNSS Rover was connected using a Lan cable at 1 hz; radio gave the received data correction and sent it to the rover via serial cable; and base was transmitting data correction via radio with a baud rate of 9600.

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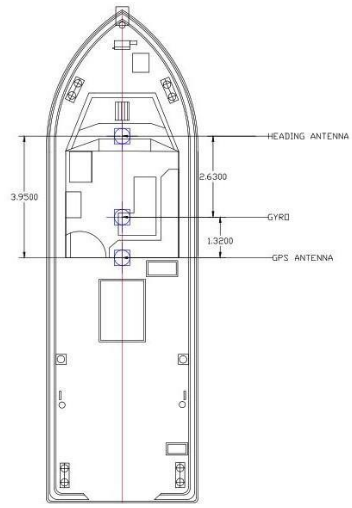

Figure 2: Instruments offsets.

Data collection

Data collected was conducted in two modes: static and dynamic to compare between headings and the Meridian Gyro Compass for the validation of RTK and DGPS, as mentioned before.

Static mode

The vessel was docked and tied to the pier with three robes, and it was steady on heading 40° in the first time and second time alongside the pier on heading 313°. during the acquisition. Instruments used are RTK, DGPS, and gyrocompass, as shown in Table 1. Headings acquired from the vessel in static mode were conducted and registered while alongside the pier, as shown in figures 3 and 4.

Table 1. Static mode

	Instruments	***Heading (°)***	***Duration (sec)***	***Time step (sec)***
A	RTK and Gyro	40	3833	1
B	DGPS and Gyro Heading	40	3695	1
C	RTK and Gyro	313	3609	1
D	DGPS and Gyro Heading	313	3655	1

Figure 3: Static 313°.

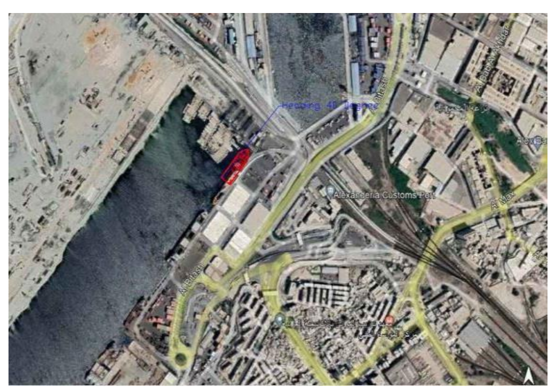

Figure 4: Static 40°.

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Dynamic mode

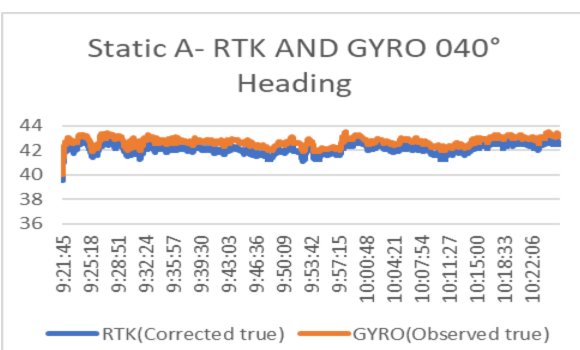
The vessel headings in dynamic mode were also recorded using the same instruments (RTK, DGPS, and gyrocompass), as shown in Table 2. Proceeding in different velocities and directions, as shown in figure5.

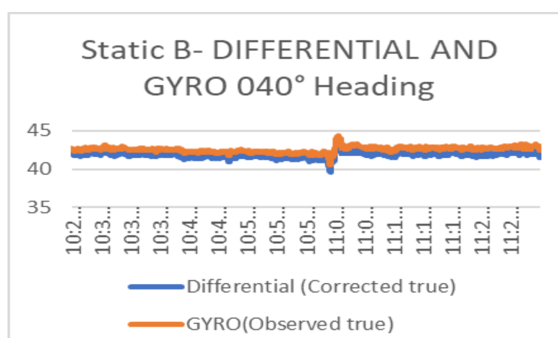
Table 2. Dynamic mode

Instruments	*Heading (°)*	*Duration (s)*	*Time step (s)*	*Length (km)*	*Speed (knots)*
RTK and Gyro	31	883	1	2.6	5
RTK and Gyro	218	1775	1	2.6	2.5
DGPS and Gyro	31	918	1	2.6	5
DGPS and Gyro	218	1835	1	2.6	2.5

Figure 5: Ship heading in Dynamic course 031°and 218°.

Line graphs in figure 6 represent the collected data after processing and converting the data from GNSS Grid to true north for both static and dynamic. Showing how data has changed over time and how headings vary within one hour. Besides, line graphs show dependencies between two different headings during one acquisition. Chart Static A illustrates the heading of RTK with Gyro on heading 040°, while chart static B illustrates the heading of Differential GPS with Gyro on the same heading. Besides, C and D static charts represents the same acquisition data on heading 330°. Overall, heading from differential GPS and RTK were almost matched with Gyro Meridian in both 040° and 330°.





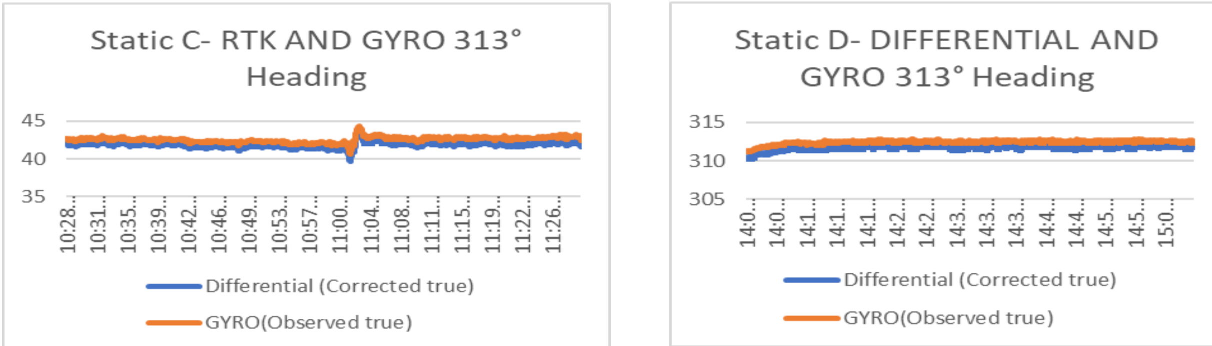


Figure 6: Converted data (Static).

In figure 7, the graphs compare in dynamic mode the RTK and the differential GPS with Gyro. In chart dynamic E and F, data was recorded at two different speeds of 2.5 knots and 5 knots in the same line with different directions of 031° and 218°. The next two dynamic charts, G and H, showed differential GPS and gyro with two different speeds and directions, 031° and 218°. In general, there was considerable matching in the data over time, speed, and direction.

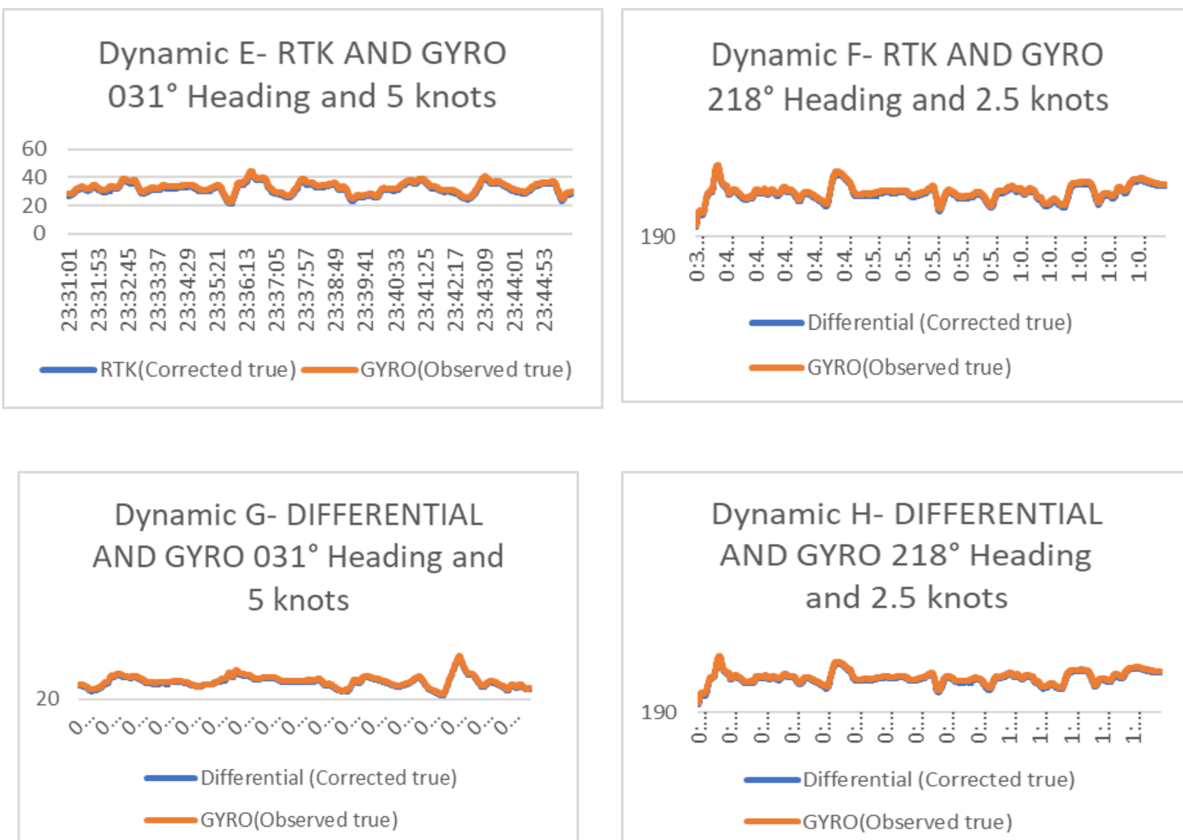


Figure 7: Converted data (Dynamic).

METHOD OF ANALYSIS

Heading corrections

While using Hypack as integration software, the collected data has been corrected with no evidence of spikes or outliers. Then, data from RTK and DGPS were converted from grid to true heading using the formula for spherical UTM projections:

$\gamma = \arctan [\tan (\lambda - \lambda 0) \times \sin \varphi]$. (Ahmed Moustafa, 2007).

where γ is grid convergence, $\lambda 0$ is the longitude of the UTM zone's central meridian, and φ and λ are latitude and longitude, as shown in figure 8.

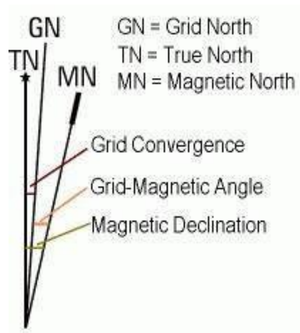


Figure 8: Grid convergence.

Statistical analysis

The statistical measures were used as essential tools for summarizing and interpreting data, assessing variability, and evaluating the performance of the data. Overall, Excel software was used to make statistical analysis and uncovering patterns for the relationships between RTK, deferential, and gyro.

Correlation coefficients

The correlation analysis in MATLAB was used to calculate the correlation coefficients between different heading acquisition techniques in order to measure the extent of the linear connection between them. Correlation analysis was used to measure the strength and direction of the relationship and provide information about how closely they are related.

RESULTS

The results for static and dynamic, as shown in table 3 and 4.

Table 3. Static results

Static A- RTK AND GYRO 040° Heading			
	RTK heading	GYRO heading	Difference °
Average	42.15	42.70	-0.55
Maximum	43.14	43.55	-0.88
Minimum	39.51	40.05	-0.23
SDTEV	0.37	0.36	0.09
RMSE	42.15	42.70	0.56
Correlation	0.96		

Static B- DGPS AND GYRO 040° Heading			
	DGPS heading	GYRO heading	Difference °
Average	41.87	42.56	-0.68
Maximum	43.67	44.32	-1.15
Minimum	39.67	40.58	-0.32
SDTEV	0.36	0.37	0.11
RMSE	41.88	42.56	0.69
Correlation	0.95		
Static C- RTK AND GYRO 313° Heading			
	RTK heading	GYRO heading	Difference °
Average	314.49	315.05	-0.55
Maximum	317.61	318.04	-0.83
Minimum	312.93	313.48	-0.23
SDTEV	0.91	0.94	0.08
RMSE	314.49	315.05	0.56
Correlation	0.99		
Static D- DGPS AND GYRO 313° Heading			
	DGPS heading	GYRO heading	Difference °
Average	311.76	312.46	-0.70
Maximum	310.28	311.18	-1.08
Minimum	312.35	312.87	-0.18
SDTEV	0.29	0.25	0.08
RMSE	311.76	312.46	0.71
Correlation	0.96		

From the results in static mode, it was found that the correlation ranged from 0.95 to 0.99, the RMSE ranged from 0.56° to 0.71°, and the standard deviation ranged between 0.08° and 0.1°.

Table 4. Dynamic results

Dynamic E- RTK AND GYRO 031° Heading and 5 knots			
	RTK heading	GYRO heading	Difference °
Average	31.84	33.05	-1.20
Maximum	21.34	22.58	-2.24
Minimum	43.31	44.64	-0.63
SDTEV	3.88	3.88	0.13
RMSE	32.08	33.27	1.21
Correlation	0.99		
Dynamic F- RTK AND GYRO 218° Heading and 2.5 knots			
	RTK heading	GYRO heading	Difference °
Average	212.57	213.65	-1.08
Maximum	198.44	199.62	-1.37
Minimum	225.35	226.38	-0.56
SDTEV	4.84	4.80	0.10
RMSE	212.63	213.71	1.08
Correlation	0.99		

Dynamic H- DGPS AND GYRO 218° Heading and 2.5 knots			
	DGPS heading	GYRO heading	Difference °
Average	213.64	214.58	-0.93
Maximum	195.29	196.19	-1.23
Minimum	228.42	229.26	-0.68
SDTEV	4.27	4.26	0.08
RMSE	213.68	214.62	0.94
Correlation	0.99		
Dynamic G- DGPS AND GYRO 031° Heading and 5 knots			
	DGPS heading	GYRO heading	Difference °
Average	32.19	33.01	-0.81
Maximum	50.42	51.36	-1.25
Minimum	22.48	23.38	-0.09
SDTEV	4.08	4.13	0.18
RMSE	32.45	33.27	0.83
Correlation	0.99		

In dynamic values, the correlation was 0.9, the RMSE was between 0.83° and 1.08°, and the standard deviation (STD) was between 0.09° and 0.18°.

This shows that the two methods are very reliable. In a nutshell, headings from both of them can be relied on for obtaining ship courses with very high accuracy, besides position, speed over ground, and time, in addition to their reasonable price.

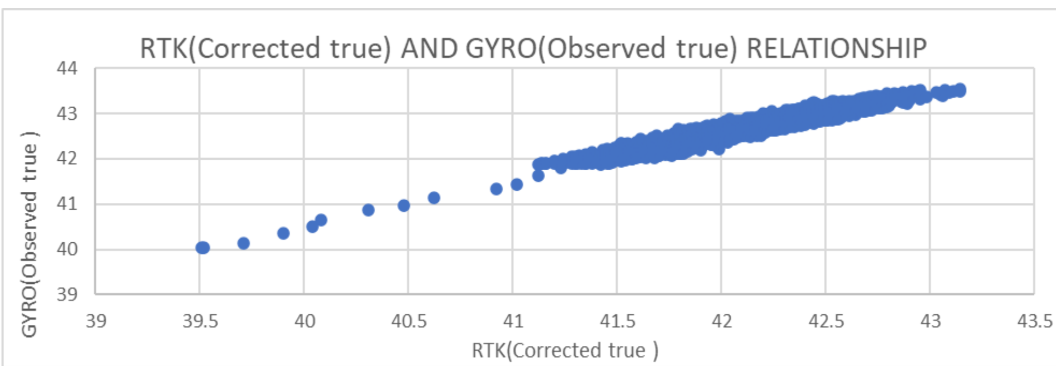


Figure 9: Static A scatter graph.

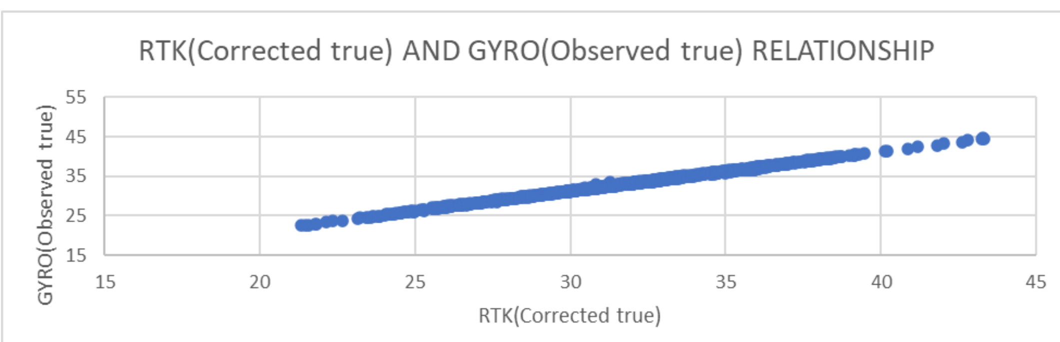


Figure 10: Dynamic E scatter graph.

The scatter graph represents the positive, strong, and linear correlational relationships between the variables, both static and dynamic, in figures 9 and 10. A strong relationship means the variables are highly correlated, clustering the data points around the trend line. The scatter plot shows a strong linear relationship because the data points cluster around the line of best fit.

CONCLUSION AND RECOMMENDATIONS

The very small differences between values observed in datasets had almost the same standard deviation of ±0.1° in static and ±0.18° in dynamic, which demonstrated the good quality of both data sets, indicating an equal amount of variability and dissipation around the means. According to the analysis of the two sets, there is a greater correlation between RTK and differential GPS heading while operating in dynamic mode as compared to static mode. The GNSS dual antenna provides accurate heading information in combination with GNSS and is cheaper than the meridian Gyro compass. In addition to direction, a GNSS dual antenna may also offer information about speed over ground, time, and position. Redundant and complementary information for the two sets ensures reliability when utilizing static and dynamic data. In addition, we need to experiment the correlation between the variables in another sea state or an open sea.

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