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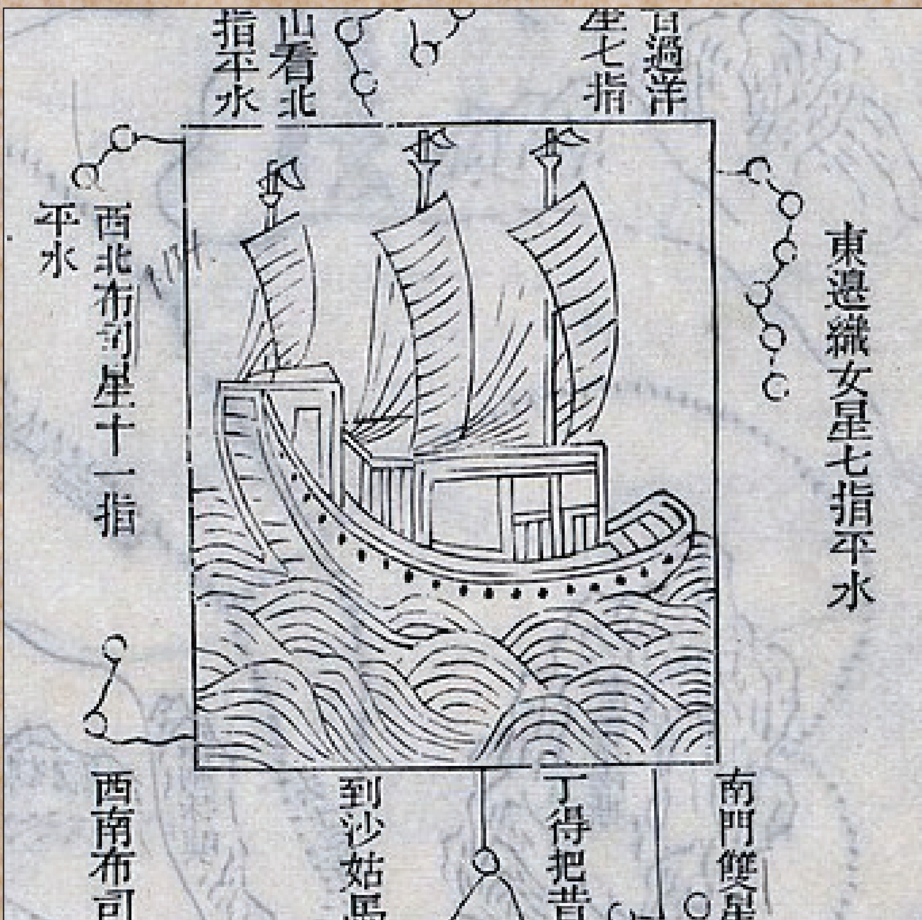

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SAILING THROUGH TIME: A COMPARATIVE STUDY OF NAVIGATION TECHNIQUES IN ZHENG HE'S NAUTICAL CHART AND EUROPEAN PORTOLAN CHARTS IN THE EARLY FIFTEENTH CENTURY

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ABSTRACT

'Zheng He's Nautical Chart' and Portolan Charts were navigational tools used in China and Europe contemporaneously during the early fifteenth century and are visual representations of the navigation techniques practiced by Chinese and European mariners. However, there is a lack of comparative study of the navigation techniques presented in the charts, which often results in misunderstandings. This article bridges the gap by providing a detailed comparison of the navigation techniques through analysing the chart, historical records, and secondary research. It concludes that the similarities between Chinese and European navigation techniques far outweigh the differences. The finding indicates the diversity and unity inherent in human responses when confronted with comparable challenges.

Keywords: Zheng He's Nautical Chart, portolan charts, navigation techniques, history of navigation techniques, China, Europe

NAVIGANDO NEL TEMPO: UNO STUDIO COMPARATIVO DELLE TECNICHE DI NAVIGAZIONE NELLA CARTA NAUTICA DI ZHENG HE E NEI PORTOLANI EUROPEI NEI PRIMI ANNI DEL QUINDICESIMO SECOLO

SINTESI

"La Carta Nautica di Zheng He" e i portolani sono strumenti di navigazione utilizzati in Cina ed Europa contemporaneamente nei primi anni del quindicesimo secolo e sono rappresentazioni visive delle tecniche di navigazione utilizzate dai marinai cinesi ed europei. Tuttavia, manca uno studio comparativo delle tecniche di navigazione presentate nelle carte, il che spesso genera malintesi. Questo articolo colma questa lacuna fornendo un dettagliato confronto delle

tecniche di navigazione attraverso l'analisi delle carte, dei documenti storici e della ricerca secondaria. Conclude che le somiglianze tra le tecniche di navigazione cinesi ed europee superano di gran lunga le differenze. La scoperta evidenzia la diversità e l'unità intrinseche delle risposte umane in presenza di sfide comparabili.

Parole chiave: Carta Nautica di Zheng He, portolani, tecniche di navigazione, storia delle tecniche di navigazione, Cina, Europa

INTRODUCTION

Nautical charts constitute a crucial cartographic tool for mariners and serves as a visual representation of navigation techniques. The earliest nautical charts, portolan charts, were first introduced in medieval Europe and commonly used for navigation across the Mediterranean and Atlantic from the thirteenth to the eighteenth centuries. While portolan charts were widely used in Europe, mariners from Zheng He's fleet produced China's oldest surviving nautical chart, known as the 'Zheng He's Nautical Chart', representing a noteworthy accomplishment of Zheng He's maritime expeditions (1405–33).

Over the years, scholars from diverse cultural backgrounds have extensively studied these two types of charts, producing numerous academic studies (e.g., Campbell, 1987; Nicolai, 2014; 2016; Mills, 1970; Pflederer, 2012). However, while there is little non-Chinese study comparing the navigation techniques depicted in these charts, the limited Chinese studies on the subject often struggle with oversimplified narratives, framing one side as either 'advanced' or 'backward' in comparison to the other (Zhang, 2004; Zhu, 2005; Yang, 2006; Lai, 2014; Liang, 2016). This article aims to provide a more detailed comparison of these two types of charts and the navigation techniques presented. It seeks to explore the similarities and differences in the applied navigation techniques between China and Europe during this period, bridging the research gap and prompting a reflection on the simplistic narrative that focuses on dissimilarities.

ZHENG HE'S NAUTICAL CHART AND THE REPRESENTED NAVIGATION TECHNIQUES

'Zheng He's Nautical Chart' (hereafter Zheng He Chart), or *Zheng He Hanghai Tu* (郑和航海图) in Chinese, was a set of nautical charts compiled in the Ming-dynasty military treatise *Wubei Zhi* (武备志) by Mao Yuanyi in 1621. Originally presented in scroll format, Zheng He Chart was adapted into 22 pages when incorporated into

Wubei Zhi, comprising 20 pages of nautical charts and 2 pages of 'stellar diagrams' (*Guoyang Qianxing Tu*, 过洋牵星图). A detailed analysis of these diagrams is provided in the following section.

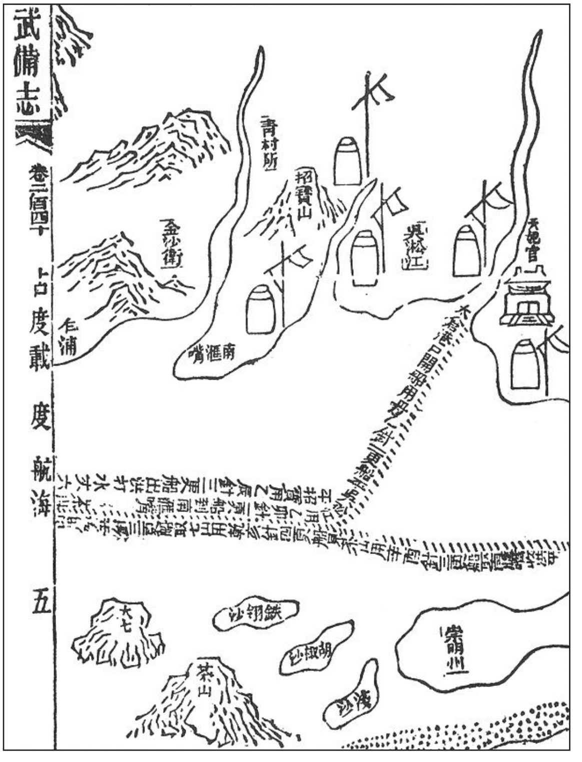


Fig. 1: Part of Zheng He's Nautical Chart in Wu Bei Zhi. Route instructions and navigational hazards can be seen in the chart (Wikimedia Commons).

Scholars have debated and discussed aspects of Zheng He Chart, including its versions, production date, and authorship (cf. Zhou, 2007). The author adopts the mainstream viewpoint in Chinese academia, treating the chart compiled by Xiang Da as the fundamental version (Xiang, 1961). The chart illustrates the primary sailing route of Zheng He's fleet during its sixth voyage to the Western Oceans (Yang, 2006; Lai, 2014), starting from Nanjing, the sailing route extends along the Chinese coast and South China Sea towards the Strait of Malacca. The route then continues westward into the Indian Ocean, reaching Ceylon and the west coast of India. Beyond this point, the route bifurcates, with one branch heading to the Arabian Peninsula and the other to the east coast of Africa. Along the sailing route, there are 109 navigational instructions to guide vessels to navigate in a specific part of the route. The chart not only depicts coastal landmarks along the way for reference but also marks navigational hazards and provides directional guidance and distance measurements along the routes. Zheng He Chart is a summary of the experiences of the expeditions of Zheng He's fleet, representing its utilization of sophisticated navigation techniques.

Numerous studies have examined the navigation techniques documented in the Zheng He Chart (e.g., Zhu, 2005; Zhang & Chen, 2017; Chen, 2019). Building on these works, the author identifies five key techniques presented in the chart and categorizes them into three overarching groups: positioning and orientation (compass orientation, landmark positioning, and *guoyang qianxing* (过洋牵星), distance and speed measurement, and navigation safety (water depth measurement using sounding leads)).

POSITIONING AND ORIENTATION

Zheng He Chart features a significant number of annotations and instructions, referred to as 'needle positions' (*Zhenwei*, 针位) along the sailing routes specified in Zheng He Chart. The needle positions specify the orientation of the compass needle, demonstrating the extensive use of the compass by Zheng He's fleet during its voyages to the Western Oceans. The use of compasses is further corroborated in historical records from Zheng He's maritime expeditions. For instance, Gong Zhen, who participated in the seventh expedition, noted in his preface to *Records of Foreign Countries in the Western Oceans* (西洋番国志): 'All [compasses] were made by cutting wood into discs, inscribing *tiangan dizhi* [天干地支, direction indicators], and floating the needle on water to indicate the direction of the vessel. [The compasses] were employed continuously, day and night for months without interruption' (Gong, 2000, 5).

The record confirms that Zheng He's fleet utilized engraved wet compasses as navigational instruments during their voyages. Gong Zhen later mentioned in the same text about the recruitment of 'fire watchers' (*huo zhang*, 火长, i.e., navigators): 'They were provided with a *Zhenjing Tushi* [针经图式, Charts and Manuals of Compass Navigation] and were assigned specific duties. These responsibilities were of utmost importance, and negligence was strictly prohibited.' (Gong, 2000, 5). *Zhenjing Tushi* refers to navigational guidebooks and charts with instructions for sailing. It is evident that the compasses and navigational charts were employed in tandem. Similar writings of other expedition members can be found in the records of other accompanying personnel (Fei, 1954; Ma, 2005).

These accounts suggest that the compasses used during Zheng He's voyages to the Western Oceans were likely wet compasses. These devices consisted of a magnetic needle floating freely on the water's surface within a bowl, enabling it to rotate and align with the Earth's magnetic field to indicate direction. When stationary, the ends of the magnetic needle pointed toward the north and south directions. These compasses were inscribed with Chinese sexagenary cycle and trigrams, dividing the full circle into 24 directional sectors, each corresponding to 15° in the modern 360-degree system. A 'single needle' (*dānzhēn*, 单/丹针) denoted a primary direction (e.g., *Single Dīng Needle* (丁针) or 195°), while a 'sewn needle' (*fèngzhēn*, 缝针) indicated an intermediate direction bisecting two adjacent sectors (e.g., *Kun-Shen Needle* (坤申针) or 232.5°). Collectively, the single and sewn needles provided 48 precise directional indicators, enabling highly accurate navigation for the fleet.

Based on this evidence, it is possible to infer how Zheng He's fleet employed navigational charts and compasses: The navigator would start by confirming the north direction on the compass. Subsequently, he would refer to the chart or guidebook to determine the specific needle position and corresponding direction. Adjustments to the course were made by reading the degrees on the compass, ensuring accurate alignment with the intended route. For example, the instruction on the chart, 'Setting sail from Taicang port and follow the *single Yi needle* (丹乙针)', would require the fleet to head southeast in the *Yi* (乙) (105°) direction after departing from Taicang port.

Another crucial positioning technique depicted in the nautical chart is landmark positioning. Some scholars have highlighted that this technique is one of the chart's most distinctive feature. For example, Liang Xun believes that landmark positioning used by Zheng He's fleet 'can be considered as the first in the world in terms of its navigation function and accuracy' (Liang, 2016, 33). Similarly, Yang Xiaohong points out that landmark positioning in Zheng He Chart demonstrates high practicality, and the depiction of various landmarks in the chart significantly enriches its content, making it more informative than contemporary European Portolan Nautical Charts (Yang, 2006, 92).

Landmark positioning refers to the use of distinctive artificial structures and natural features along the coast or at sea as reference points for navigation during voyages. For example, Gong Zhen wrote in *Records of Foreign Countries in the Western Oceans*: 'The shapes of islands in the sea are not the same. The islands can be observed at various positions. Their shapes are taken as references, and the course is adjusted accordingly' (Gong, 2000, 5). The text indicates that the fleet adjusted its course according to the relative positions and shapes of landmarks. Similar descriptions of landmark positioning can be found throughout Zheng He Chart. For example, in one segment of the route, the instruction indicates that when *Mount Tantou* lies abeam, *Jiangpian Reef* is visible to the east, *Dafo Mountain* to the west; thereafter, *Dongxiqi Mountain* appears abeam. The text implies that Zheng He's fleet employed cross-bearing method to identify the ship's position using different landmarks.

In addition to the chart illustrating the sailing route, there are four supplementary *Guoyang Qianxing Tu* attached to Zheng He Chart. These four stellar diagrams visually codify the *guoyang qianxing* technique, a sophisticated method of celestial navigation. At the centre of each diagram, a sailing ship is depicted navigating the open sea, surrounded by the stars and constellations relevant to astronomical navigation in the region. Directional bearings, star names, and altitude measurements of the stars needed for astronomical navigation are annotated. The title and relevant explanations are clearly labelled to the right of each diagram.

Scholars define *guoyang qianxing* as a method of determining a vessel's latitude position at sea by observing the elevation of astronomical objects (Liu, 1989, 46–70). The term *guoyang qianxing* literally means 'cross the seas guided by the stars'. In practical terms, sailors would use a Chinese latitude hook to observe the height of astronomical objects while at sea. When using the hook, the navigator would hold the centre of one end of the board and extend his arms, orienting his gaze toward the sky. The upper edge of the board aligns with the targeted star, and the lower edge aligns with the horizontal line. They would then compare the observed height with the corresponding instructions marked on the diagram to determine the vessel's heading and position. The units used in this technique are 'finger' (指) and 'angle' (角). This technique involves measuring the angular height of astronomical objects above the sea horizon to ascertain the vessel's position and heading.

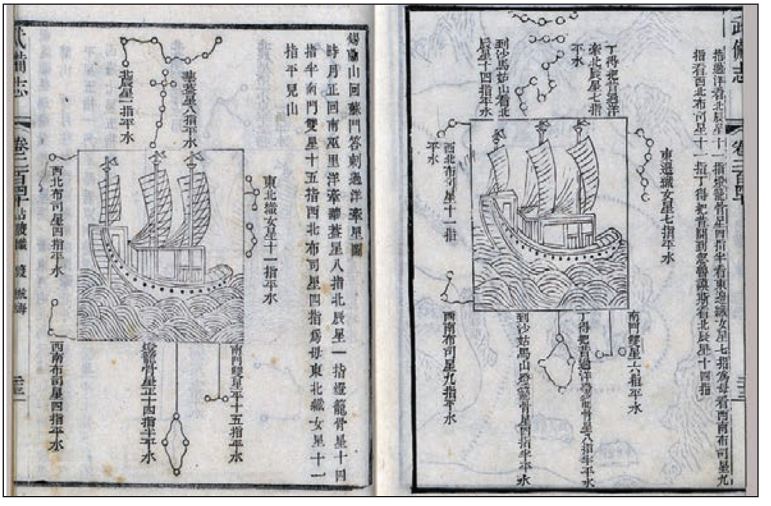


Fig. 2: Two of the four Guoyang Qianxing Tu *in Zheng He Chart (Wikimedia Commons).*

The four *Guoyang Qianxing Tu* included in the *Wubei Zhi* are titled: *From Ceylon*[1] *to Sumatra, Guoyang Qianxing Tu*, *From Longxian Yu to Ceylon*, *Guoyang Qianxing Tu*, *From Guli to Hormuz*, *Guoyang Qianxing Tu*, and *From Longxian Yu to Ceylon*. It should be noted that all the locations depicted in these four diagrams are situated in the open sea within the Indian Ocean west of the Strait of Malacca, where the fleet must travel in open waters away from shore. This indicates that, in the absence of natural and artificial features for landmark positioning, Zheng He's fleet relied on astronomical navigation techniques.

The use of astronomical navigation is also recorded by Gong Zhen in the preface to *Records of Foreign Countries in the Western Oceans*. He wrote:

> *The vast sea stretches endlessly, with water and sky connecting seamlessly. Looking around, there is no trace of any structures. It is only by observing the rising and setting of the sun and moon to distinguish between west and east, and the height of the stars that positioning became possible* (Gong, 2000, 5).

The text implies that, while sailing in the open sea without visible landmarks, Zheng He's fleet relied on observing astronomical objects to ascertain their position.

1 After consulting works of Naval Marine Surveying and Mapping Institute in 1985 and 1988, it is clear that Ceylon is present-day Sri Lanka. Longxian Yu is present-day Pulau Beras in western Sumatra, Indonesia, and Guli is present-day Kozhikode or Calicut in India. The following comparisons of ancient and modern place names are all derived from these sources.

DISTANCE AND SPEED MEASUREMENT

Distance and speed measurement is closely related to positioning and orientation during maritime navigation. An accurate measurement of speed and distance is crucial for correctly determining a ship's heading. In Zheng He Chart, the instructions for the sailing routes extensively use *geng* (更) as the unit of time interval. In Ming Dynasty, ten *geng* constituted one day, making one *geng* equivalent to 2.4 hours. During Zheng He's maritime expeditions, the measurement of time usually relies on traditional Chinese methods, such as incense burning. When a ship maintained a constant speed over a period, multiplying the number of *geng* by the speed would yield the distance travelled.

There is debate regarding whether *geng* represents a unit of time or distance (Liu, 2016). Nevertheless, measuring a ship's speed is essential for any voyage. According to records of the early Ming-dynasty work *Shunfeng Xiangsong* (顺风相送), the method used for speed measurement was the 'throwing wood for speed measurement' method (Xiang, 2000). Modern Chinese scholars have identified this as a method involving throwing a piece of wood from the ship's bow into the sea, and then a person on board walks at the same speed as the drifting wood moves towards the ship's stern (He, 2016; Zhang & Chen, 2017). The ship's speed can be calculated by dividing the known length of the ship by the time it takes for both the person and the wood to reach the ship's stern simultaneously. It is then possible to infer the location of the ship based on the speed and the time travelled. Although the method seems primitive, it was a practical way of measuring speed in the absence of precise measuring tools.

NAVIGATION SAFETY

Safety is of utmost importance for any maritime activity. Two methods to ensure safety can be identified from Zheng He Chart. The first method involved marking navigational hazards such as rocks, shoals, and sandbars on the nautical chart, enabling the fleet to navigate around them. For example, in the charts, dense black dots represented shallow sandbars, large rocks indicated reefs, and a pattern of dense black dots interspersed with a few small circles denoted atolls and hidden sandbars.

Another method involved marking water depths to enable the fleet to assess whether it was safe to navigate through a particular area. Depth measurements on the nautical chart were represented by the unit *tuo* (托). Recent research has shown that the depth measuring tool used by Zheng He's fleet was sounding lines – thin ropes with a plummet at their ends (Wang, 1995; Zhu, 2005; Chen, 2019). A lead weighing about eight to nine kilograms was tied to a long cotton rope coated with oil and lowered into the water. The boundary between water and oil, observed upon retrieving the sounding lead, indicated the water depth. If sand was found on the lead when it was retrieved, it signalled shallow waters, indicating a suitable spot for the ship to anchor. If no sand was found, it meant the water was too deep or had a rocky bottom, and anchoring the ship was not advisable. The terms *da tuo* (打托) and *da shui* (打水) on the nautical chart referred to the sounding lead depth measurement technique, with one *tuo* representing the span of a person's outstretched arms. For example, 'seeing *Daqi and Xiaoqi Mountains* and the sounding is six or seven *tuos*' meant the water depth after sighting *Daqi and Xiaoqi Mountains* is six or seven *tuos*. In this way, water depth measurement was also helpful for the fleet to determine its location.

It should be noted that any successful navigation relies on the combined use of different techniques. For example, two navigation route instructions in Zheng He Chart read as 'Passing *Cha Mountain* to the northeast, using the "*Xun-Si needle*" [巽巳针] position [142.5°], after four *gengs*, the ship sees *Daqi and Xiaoqi Mountains*, and the sounding is six or seven *tuos*', and 'Heading within the five fingers of *Huagai* star[2], reaching within four fingers of *Beichen* star[3] using then *Gui-Chou needle* [癸丑针] position [22.5°], after sixty-five *gengs*, the ship reaches *Geerdefeng*[4] and *Hafueryu*[5]'.

These instructions indicate the integrated application of the five navigation techniques – compass orientation, landmark positioning, *guoyang qianxing*, distance and speed measurement, and water depth measurement with sounding leads – in both coastal and open-sea voyages. This integration is clearly represented in Zheng He Chart. From this point of view, Zheng He's fleet demonstrated a high level of skill in using diverse navigation techniques to conduct ocean navigation.

PORTOLAN CHARTS AND THE REPRESENTED NAVIGATION TECHNIQUES

The term 'Portolan Charts' does not refer to a specific chart, but to a category of charts used in Europe from the thirteenth century. Its name originates from the Italian word *portolano*, meaning a rutter. The rutter serves as a collection of written sailing directions, whose texts list places, with distances and directions to reach them.

The oldest surviving Portolan chart is the *Carta Pisana*, which is believed to have been produced at the end of the thirteenth century. According to the statistics provided by Richard Pflederer, from the oldest *Carta Pisana* to the late eighteenth century when portolan charts were replaced by other tools, a total of 1,826 charts with identifiable production dates were produced (Pflederer, 2012, 140). Among these, there are 60 charts that are contemporaneous with Zheng He's voyages, created between 1400 and 1450. For a comparison with Zheng He Chart, the portolan charts discussed in this section will be the charts produced before 1500.

Portolan charts are typically drawn on a single skin of leather, vellum, or parchment. Scholars have concluded the following characteristics of portolan charts (He & Han, 2020; Campbell, 1987): The most obvious of the common denominators that link *Carta Pisana* to later works is the network of interconnecting rhumb lines. The networks of lines on the charts, which radiate from the numerous 'wind roses'

2 Huagai Star is part of Cassiopeia constellation.
3 Beichen Star is Polaris.
4 Geerdefeng is Cape Guardafui in present day Somalia.
5 Hafueryu is Cape Hafun in present day Somalia.

situated at different points on the map, are generated through compass observations. These lines represent paths of constant bearing, indicating specific directions for navigation. The lines are arranged in a coherent pattern, with sixteen equidistant intersection points around the circumference. The circle is, therefore, divided into sixteen equal parts, and each is joined to others through the centre point on the opposite side. Each circle is joined to most or all the others, providing a total of thirty-two directions, which are drawn in different colours. Another characteristic is the frequent exaggeration of coastal features and the simplification of land. Because of their navigational purposes, features related to sailing are emphasized in the charts. For example, islands and capes are often enlarged, while navigational hazards such as reefs and shoals are clearly indicated. Compared to maritime features, inland parts of the charts are often left blank or filled with imaginative contents.

As a crucial navigational tool from the medieval period to the early modern period, portolan charts are visual representations of the medieval and early modern European navigation techniques. To facilitate a comparison with the Zheng He Chart, this section will also categorize the navigation techniques presented in portolan charts into three categories: positioning and orientation, distance and speed measurement, and navigation safety.

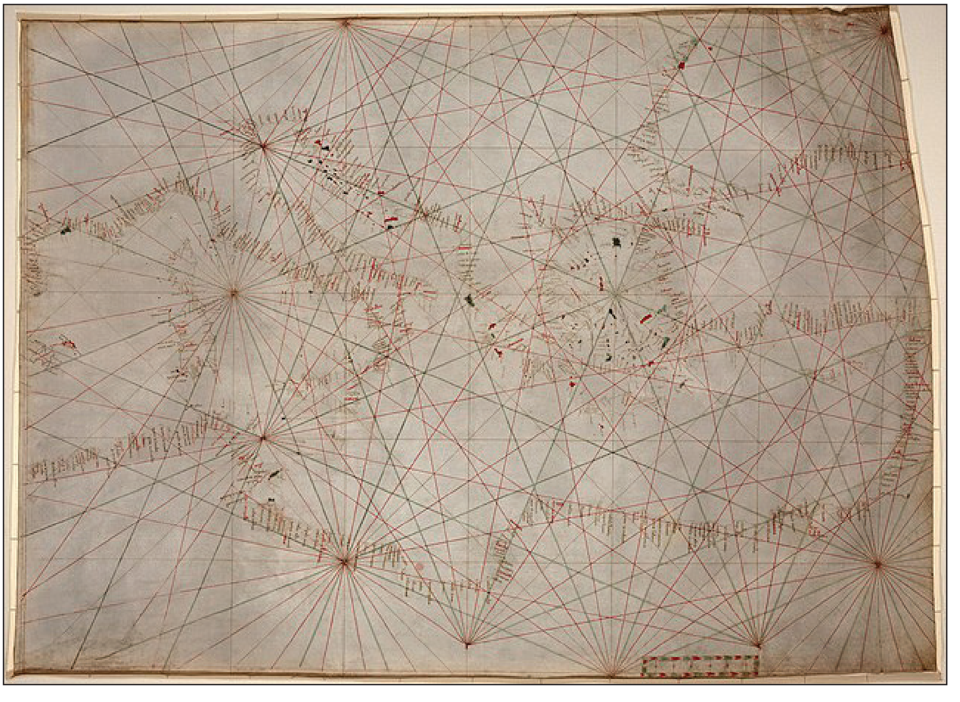


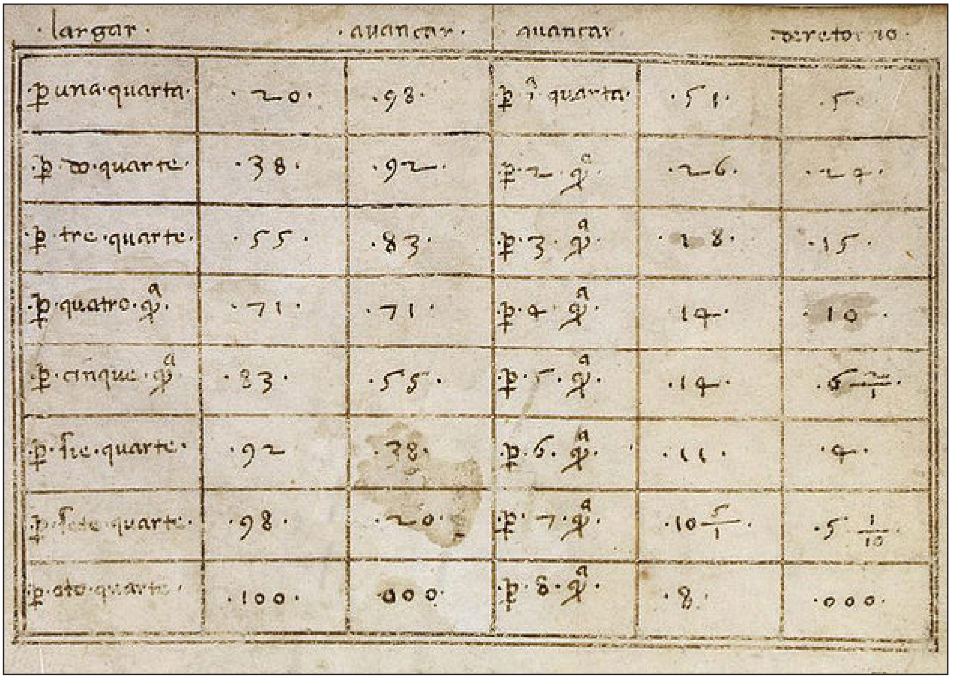
Fig. 3: A fourteenth-century portolan chart probably from Genoa. The rhumb line networks and wind roses can be seen in the chart (Wikimedia Commons).

POSITIONING AND ORIENTATION

As stated above, the term ‘portolan’ was derived from the Italian word for rutter – *portolano*. Scholars have discussed the relationship between the chart and the rutter (cf. Nicolai, 2014). Nevertheless, it can be concluded that both were closely related and cooperatively employed in navigation. Rutters, apart from depicting and identifying aspects such as water depth, anchorages, and landmarks, also contain extensive information on coastal and oceanic routes. Descriptions of these routes encompass details like compass directions, distances, geographical features, and landmarks, providing navigators with crucial guidance. Similar to Zheng He’s fleet, which used charts and *Zhen Jing* for navigation, European ships also utilized portolan charts and rutters together as essential tools for navigation.

Networks of rhumb lines is one of the significant features of portolan charts. The straight lines that intersect on portolan charts depict the sixteen (and later thirty-two) directions (or headings) of the mariner’s compass from a specific point. The main lines are aligned with the magnetic north pole, providing a navigational reference for mariners. The feature may indicate a strong relationship between the compass and portolan charts and some scholars even termed portolan charts as ‘compass charts’ (cf. Nicolai, 2016, 11–12). Although there are debates regarding whether the compass played a role in the invention of portolan charts (He & Han, 2020, 79; Campbell, 1987, 384–385), there is evidence indicating a close connection between the compass and portolan charts. The earliest European records of compass use date back to 1190, indicating that by the time portolan charts emerged, compasses were already in use in Europe. There are some historical texts that prove the co-use of charts and compass. For example, in the early fourteenth century, Italian writer Francesco da Barberino mentioned three navigational tools – maps, compasses, and hourglasses (Barberino, 1905, 125–126). In 2018, French scholars Michienzi and Vagnon studied communications among Italian mapmakers in the late fourteenth to early fifteenth centuries found in the Datini Archive in Prato, Italy (Michienzi & Vagnon, 2018, 22–33). They discovered that portolan charts were often sold along with compasses and dividers. These charts not only required high quality and precise craftsmanship but also the endorsement of experienced mariners and cartographers. One buyer even explicitly requested that a purchased chart be securely affixed to a compass for practical use. Based on these findings, it can be inferred that portolan charts were used in navigation and were commonly employed in conjunction with compasses.

There is little record on how exactly portolan charts were used in actual navigation practices. Therefore, researchers must rely on the information depicted on the charts and limited surviving historical texts for reference. For example, in the biography of the Castilian privateer Pero Niño by medieval



Quarter (Angle of Deviation)	Alargar (Distance from course)	Avanzar (Advance on true course)	Quarter (Angle of return)	Ritorno (Return to course)	Avanzo di ritorno (Advance during return)
1	20	98	1	51	50
2	38	92	2	26	24
3	55	83	3	18	15
4	71	71	4	14	10
5	83	55	5	12	6 ½
6	92	39	6	11	4
7	98	20	7	10⅕	2 ⅕
8	100	0	8	10	0
	For every 100 miles			For every 10 miles alargar	

Fig. 4: The original toleta table (above) in Andrea Bianco's chart (Wikimedia Commons) and its transcription (below).

Spanish historian Gutierre Díez de Gamez, it is mentioned that in 1404, sailors aboard Pero Niño's ship 'set up their compasses furnished with magnet stones' and 'opened their charts and began to prick and measure with the compass' during a storm (Gamez, 2000, 39–40). Additionally, in 1483, the German priest Felix Fabri mentioned that sailors, when unable to see land or stars, could still determine their position by drawing curves from one line to another and from one point to another on the chart (Fabri, 1897). As Campbell (2023) argued, the direction finding in European navigation had become entirely magnetic by the time of the Carte Pisane (ca.1270), and the wind roses and rhumb lines on portolan charts were used in correlation with the compass to navigate. Based on these records and studies, scholars (Ash, 2007, 513; Bennet, 2017, 55–60) have concluded the following methods for using portolan charts.

To begin, the navigator draws a straight line between the departure port and the destination port on the chart. Then, he will identify a line that runs parallel or close to parallel to the intended route among the numerous rhumb lines on the chart. Subsequently, he follows this line back to the wind rose, adjusting the heading based on the angle of the line indicated on the rose. Additionally, there is often a scale marked on the chart, allowing the navigator to use rulers and dividers to calculate the distance between the two points. From this distance, they can then determine the time required to reach the destination based on the ship's speed.

In practice, navigators must account for currents, wind, and other environmental factors. These natural conditions may cause the ship to deviate from the planned course, requiring adjustments to the heading. Therefore, a revision of the course is needed. This revision is typically accomplished using a method called *toleta de marteloio*, commonly referred to as 'toleta'. Toleta is a simple method that utilizes trigonometry calculations to determine the angles needed for heading adjustment and the distance required to return to the true course, using the compass and timer. Some charts already include precomputed toleta tables, making it accessible even for less-educated sailors. Toleta can be employed in various ways. For example, in the portolan chart used by the Venetian captain Andrea Bianco in 1436 (Fig. 4), angles and distances are correlated, enabling navigators and sailors to quickly determine the corresponding distance to be travelled after identifying the travel angle.

From left to right, each column represents the following parameters: Angle of Deviation (Quarter), Lateral Distance from Course (Alargar), Advance on the True Course (Avanzar), Angle of Return (Quarter), Return to the Original Course (Ritorno), and Advance Achieved During Return (Avanzo di Ritorno). Assuming the ship is travelling in any direction but is forced to divert because of the wind and current. If the navigator tracks the deviated angle and travelled time, he could easily determine how far the ship has deviated. He could then choose a return angle and then calculate the distance the ship needs to return to true course and the distance the ship would cover upon returning to the intended course. With the aid of the compass, portolan chart, and toleta table, the navigator can follow the course and adjust for deviations caused by natural conditions.

DISTANCE AND SPEED MEASUREMENT

From the discussion on the use of portolan charts during voyages, it is evident that an accurate measurement of speed is necessary for any successful journey. Without speed information, it would be impossible to make a calculation of the required distance and time for reaching the destination, thereby posing a risk of deviation from the intended course when employing toleta tables. According to research, in early fifteenth-century Europe, the method for measuring a ship's speed typically involved observing the vessel's progress relative to floating objects on the sea surface and extrapolating to estimate its speed (Ash, 2007, 510). Normally, the method would involve dropping wooden chips from the ship's bow, timing their passage between two fixed points on the vessel using a sandglass or a simple rhyming phrase. As the distance between these two points is known, the speed could be calculated by dividing the distance by the recorded time. This method bears strong resemblance to that employed by Zheng He's fleet. The method was still being used in the 1490s when Columbus took his voyage to America (Kelly, 1987, 130–131).

NAVIGATION SAFETY

The documentation of maritime hazards in guidebooks plays a crucial role in ensuring safe voyages. However, using symbols to mark dangerous elements on charts may be more intuitive and widely applicable than textual descriptions, especially for the less educated medieval sailors. Black symbols representing hazards were already present in *Carta Pisana*. According to the studies by Campbell and Barritt, portolan charts primarily employ the following symbols to represent navigational hazards (Campbell & Barritt, 2020): black symbols in the form of a cross, sometimes surrounded by black dots, are used to represent isolated rocks. When multiple such symbols are placed together, they collectively represent extensive rock formations or sandbanks. Red symbols in the form of dots are used to indicate shallow waters. In addition to the generic symbols for hazards, special forms are employed in specific regions. For instance, in a 1467 Grazioso Benincasa chart (Fig. 5), *Chaussée de Sein*, a channel off the French west coast near Brest, was marked as particularly hazardous. *Île de Sein* is represented by a red triangle, smaller islands are painted in red circles with shades, and the extensive rocky formation extending westward is depicted by a long strip of black dots. These symbols not only indicate the hazards but also constitute the only indication of information related to water depth on portolan charts (Campbell, 1987, 378).

Fig. 5: Chaussée de Sein as shown in a 1467 Grazioso Benincasa chart (Wikimedia Commons).

In general, portolan charts are the visual representations of the accumulated navigation experiences passed down through generations of mariners in the Mediterranean and surrounding regions. The charts illustrate the sophisticated navigation techniques prevalent in late medieval Europe, including the use of sea charts, compasses, and rutters for positioning and orientation. These techniques also involve route calibration with toleta tables, measuring ship speed with floating objects, and marking hazards with symbols to ensure safe navigation. The practicality of these charts contributed to their enduring use in Europe for several centuries until their eventual disappearance in the late eighteenth century. Some charts, such as the 1375 Catalan Atlas produced by the Majorcan School, were highly valued for their exquisite craftsmanship (Beguš, 2014) and were collected by members of the European upper class.

DISCUSSION

Technique Comparison

Though developed from different cultural backgrounds, the navigation techniques presented in these charts bear a strong resemblance, with only minor differences in details. First, both Chinese and European mariners heavily relied on the compass, which is clearly presented on the nautical charts. The dense compass positions in the instructions in Zheng He Chart and the obvious wind roses and rhumb line networks in the portolan charts highlight the central role the compass played in maritime practices in both regions. Additionally, both charts emphasize the roles of guidebooks and rutters. The difference is that the route instructions are inscribed on the chart in the Chinese case, while the rutter remains separate in the European context.

Second, the methods for measuring a ship's speed in both traditions are nearly identical – estimating speed based on the time it takes for a floating object to travel between two fixed points. The key difference lies in the timing tools used: Zheng He's fleet relied on incense, while European navigators used hourglasses and rhyming phrases.

Third, both charts use similar methods for marking navigation hazards. They even choose to label some hazards in the same pattern, such as using dense dots to depict shoals. However, cultural differences can also be read through the hazard symbols. For example, Zheng He Chart uses traditional Chinese landscape painting techniques to depict reefs, while the Portolan Chart uses symbols such as crosses for representation. After marking these hazards, sailors would rely on their personal experiences to navigate, a practice that is entirely identical for both Chinese and European mariners.

Technique Exchange

Both Zheng He Chart and portolan charts illustrate navigation techniques that originated from other regions and cultures, indicating probable exchanges and communications of these techniques before 1500.

One of the typical examples of technique exchange and communication is the introduction of compass from China to Europe. Although there is a lack of direct evidence of such introduction, scholars (e.g., Bentley & Ziegler, 2010) believe that the magnetic compass originated in China and spread to Europe during the medieval period. This argument is based on the earliest record of compass use and the similar shape of the device in the two regions (Needham, 1962; Li, 1992; Pan, 2002; Huang, 2017). The introduction of the magnetic compass to Europe is related to the hypothetical predecessor of the portolan chart which seems to have emerged in the early thirteenth century. It can be argued that the application of compass in navigation significantly contributed to the development of European navigation, which has been demonstrated above, and are closely related to the appearance of portolan charts (Lane, 1963, 606). European mariners utilized the Chinese invention, and the use of the compass in navigation is visually presented in portolan charts.

Likewise, several navigation techniques represented in the Zheng He Chart are also the result of technological exchange and communication between China and other cultures. These include *guoyang qianxing* and water depth measurements with sounding leads. For example, Liu (2013) argues that the *guoyang qianxing* technique was learned from the 'foreign firewatchers' (番火长) employed by Zheng He's fleet. *Guoyang qianxing* was commonly used in the Indian Ocean region and was first recorded in China after Zheng He's voyage. Liu infers that Chinese mariners may have learned the technique from their foreign employees, records of whom disappeared after Zheng He's fourth voyage. Liu concludes that their disappearance resulted from Chinese navigators' acquisition of the technique, rendering foreign assistance unnecessary for the fleet. However, other scholars (e.g., Chen, 2016) argue that *guoyang qianxing* was a pre-existing technique in the Islamic world that was adopted by Zheng He's fleet. Others (e.g., Park, 2012) suggest that the introduction of this technique might have resulted from the pre-Ming exchange of knowledge, especially in terms of astronomy (Hamdani, 1992; Liu, 2019; Mak, 2022). In either case, *guoyang qianxing* serves as an excellent example of how Chinese navigation benefited from cross-cultural technique exchanges.

Similarly, Chen (2019), after examining archaeological evidence and historical records, argues that Chinese water depth measuring technique was also learned from others. The tools, units of measurements and practices employed by Zheng He's fleet were almost identical to those found in the Mediterranean, where records of the technique can be traced back to ancient Greece. From a chronological perspective, the water depth measuring technique applied by Chinese mariners likely came from similar practices in the Mediterranean region.

Technique Choice

Both Zheng He Chart and portolan charts represent techniques that are not demonstrated in the other. For example, portolan charts lack any depiction of astronomical navigation techniques. However, this absence does not necessarily indicate a lack of awareness or reluctance among Europeans to adopt astronomical navigation methods. Research has affirmed that astronomical navigation was adopted by the Portuguese in the fifteenth century in response to the challenges outside the Mediterranean (Canas, 2017). Rather, the lack of astronomical navigation in portolan charts is more due to its limited function in the Mediterranean. Campbell (1987, 441) concluded the belated adoption of astronomical navigation in Europe. First, it was because of the relatively small size of the Mediterranean. Vessels rarely sailed without the line of sight of land for more than a week, making it almost impossible for navigation errors to accumulate. Second, early astronomical navigation instruments, such as astrolabes, had an error margin of 18 kilometres, which is deemed too excessive for Mediterranean navigation. However, the situation changed after the Portuguese began to explore along the West African coast in early fifteenth century. In these navigations, there are cases where the ship must sail without the sight of land for longer periods. Under such circumstances, astronomical navigation was promptly introduced and widely adopted. It became a prominent technique for European navigators during the subsequent expeditions outside the Mediterranean, while navigation within the Mediterranean remained little different from the medieval pattern until the eighteenth century (Campbell, 1987, 441).

Similarly, Liu's (2016) research suggests that along coastal routes, astronomical navigation becomes less practical due to reefs, sandbanks, and complex maritime conditions. In such areas, landmark positioning is more effective, particularly in regions with significant navigational hazards. However, in the expansive waters of the Indian Ocean, where artificial and natural reference points could no longer be sighted, astronomical navigation becomes more applicable and perhaps the only method for orientation and positioning. This explains why the *guoyang qianxing* technique depicted in the Zheng He Navigation Chart is only presented in areas to the west of the Strait of Malacca, while needle position instructions dominate instructions east of the strait.

CONCLUSION

Zheng He Chart and portolan charts are visual representations of the achievements of Chinese and European maritime navigation during the same historical period. After examining the navigation techniques presented in the charts, the author concludes that, despite minor differences in detail, the overall navigation capabilities of China and Europe during this period were comparable in sophistication. Mariners from distinct cultural backgrounds, when confronted with similar navigational challenges, instinctively employed similar tools and methods. Moreover, both sides benefited from the exchange of experiences and practices, highlighting extensive and close interactions between diverse cultures. Ultimately, the choice of navigation techniques often depended on the specific needs of particular regions. The absence or lack of adoption of certain techniques does not necessarily indicate technological inferiority; rather, it may reflect their incompatibility for specific local contexts.

Navigation techniques embody the ingenuity and strategic decisions of mariners in addressing the challenges of maritime navigation. Moving forward, while investigating these techniques, it is crucial to examine the historical contexts, considering factors such as the geographical, hydrological, and meteorological conditions, as well as economic and cultural backgrounds in which navigation techniques were situated. Adopting a comparative and cross-regional approach helps prevent simplistic classifications of technology as either 'advanced' or 'backward.' As demonstrated in this article, differences in navigation techniques often indicate the different strategies adopted by mariners in response to varied environmental conditions. The absence of a particular technique in a region may result from the conscious choices based on experience and needs. The study of technological history will inevitably involve considerations of the origins and spread of certain techniques. Researchers should recognize that the origin and development of technology constitute a dynamic process, which is influenced by multiple interacting factors. The analysis of whether the absence or presence of a technology stems from incapability or conscious choices requires a comprehensive examination of the specific context. The examination of technological similarities and differences, as represented in the charts, highlights humanity's common responses to shared challenges and underscores the diversity in the cognitive processes and cultures in addressing problems. The unity and diversity of human culture require researchers to move beyond studies confined to single nation-states or cultural spheres and re-examine technological innovations and cultural interactions throughout human history.

PLOVBA SKOZI ČAS: PRIMERJALNA ŠTUDIJA NAVIGACIJSKIH TEHNIK NA DŽENG HEJEVI POMORSKI KARTI IN EVROPSKIH PORTULANSKIH KARTAH V ZGODNJEM 15. STOLETJU

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POVZETEK

»Dženg Hejeva pomorska karta« in portulanske karte so reprezentativni primeri sočasnih kitajskih in evropskih pomorskih kart. Raziskovalci iz različnih držav so obe vrsti kart podrobno proučevali, kar je pripeljalo do obilice znanstvenih študij te problematike. Kljub temu pa trenutnim raziskavam manjka primerjalna študija, saj so se redke dostopne primerjave osredotočile zlasti na razlike med obema vrstama kart ter jih tolmačile v okviru naracije »naprednega« proti »zaostalemu«. Ta članek na podlagi podatkov s kart, zgodovinskih dokumentov in sekundarnih raziskav nudi podrobno primerjalno študijo navigacijskih tehnik. Najprej predstavi navigacijski tehniki upodobljeni na Dženg Hejevi pomorski karti ter na portulanskih kartah iz zgodnjega 15. stoletja skozi pozicioniranje in orientacijo, meritve razdalj in hitrosti ter varnost navigacije. Članek nadaljuje s primerjalno analizo teh tehnik, ki pokaže velike podobnosti med njima, nato pa s premislekom o medkulturnih izmenjavah in lokalnih izbirah predstavi možne razloge za redke razlike med tehnikama. Avtor zagovarja tezo, da so bili kitajski in evropski mornarji, soočeni z izzivi plovbe, aktivni udeleženci v komunikaciji, razširjanju, izbirah in lokalizaciji navigacijskih tehnik, ter sklene, da sta bili njihovi navigacijski tehniki v 15. stoletju na enaki ravni. Kljub določenim razlikam, podobnosti med kitajsko in evropsko navigacijsko tehniko namreč močno prevladajo nad razlikami. Spoznanje kaže na raznolikost in enotnost v odzivih ljudi, kadar so soočeni s primerljivimi izzivi.

Ključne besede: Dženg Hejeva pomorska karta, portulanske karte, navigacijske tehnike, zgodovina navigacijskih tehnik, Kitajska, Evropa

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