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NAVIGATIONAL INSTRUMENTS AND THE IMPORTANCE OF CALCULATING SHIP'S SPEED IN MARINE NAVIGATION

DENİZ SEYİRCİLİĞİNDE SEYİR ALETLERİ VE GEMİ HIZININ HESAPLANMASININ ÖNEMİ

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Abstract

Navigation, an essential aspect of human exploration and maritime activities, has evolved significantly from its ancient origins to the sophisticated technologies of today, reflecting a long and continuous process of observation, experimentation and adaptation to the maritime environment. This paper explores the historical development of navigational instruments, focusing on their role in shaping maritime navigation practices and the critical importance of calculating a ship's speed, which has consistently remained a central concern for seafarers across different historical periods. From the early discovery of floating objects to the invention of shipbuilding techniques, the foundations of navigation laid the groundwork for advancements in maritime travel, enabling humans to move beyond coastal waters and undertake longer and more complex voyages. In particular, the ship log, a tool designed to measure speed, stands out for its distinct ability to quantify movement over water, separating it from other navigational methods, as it provides measurable data rather than relying solely on visual observation or experience. The ability to calculate speed plays a key role in measuring distance and time, facilitating the advancement of maritime navigation, since accurate estimations of a vessel's progress are essential for route planning, safety and the successful completion of sea journeys.

Keywords: *Sea Navigation, Navigational Instruments, Ship Speed Calculation, Ship Log, Dutchman's Log*

Öz

Navigasyon, insanlığın keşif faaliyetlerinin ve denizcilik etkinliklerinin temel bir unsuru olarak, antik kökenlerinden günümüzün gelişmiş teknolojilerine kadar uzanan süreçte, denizcilik ortamına yönelik gözlem, deneme ve uyumun uzun ve kesintisiz bir sürecini yansıtarak önemli ölçüde gelişmiştir. Bu çalışma, seyir araçlarının tarihsel gelişimini incelemekte, denizcilik seyir uygulamalarının şekillenmesindeki rollerine ve bir geminin hızının hesaplanmasının kritik önemine odaklanmaktadır; zira bu unsur, farklı tarihsel dönemler boyunca denizciler için sürekli olarak önemli bir problem olmuştur. Yüzen cisimlerin keşfinden gemi yapım tekniklerinin icadına kadar uzanan navigasyonun temelleri, insanların kıyı sularının ötesine geçmesini ve daha uzun ve daha karmaşık seferler gerçekleştirmesini mümkün kılarak deniz yolculuğundaki ilerlemelerin zeminini oluşturmuştur. Özellikle, hızı ölçmek üzere tasarlanmış bir araç olan parakete, yalnızca görsel gözleme veya deneyime dayanmaktan ziyade ölçülebilir veriler sunması nedeniyle su üzerindeki hareketi nicel olarak ifade edebilme özelliğiyle diğer seyir yöntemlerinden ayrılmaktadır. Hızın hesaplanabilmesi, mesafe ve zamanın ölçülmesinde kilit bir rol oynamakta ve denizcilik seyrinin gelişimini kolaylaştırmaktadır; çünkü bir geminin ilerleyişinin doğru biçimde tahmin edilmesi, rota planlaması, emniyet ve deniz yolculuklarının başarıyla tamamlanması açısından vazgeçilmezdir.

Anahtar Kelimeler: *Deniz Seyrüseferi, Seyir Aletleri, Gemi Hızı Hesaplaması, Parakete, Dutchman Paraketesi*

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Introduction

Navigation is a common word for all people and is generally used every day at least once while going somewhere. In the last decade, people have often been using their mobile phones, just as an old-time navigator, to find their way with the help of some signals. With the technological revolution, the words satellite, GPS (Global Positioning System), internet, etc. came into our lives and they shaped the definition of navigation but its roots descend from the ancient times. According to Oxford Dictionary, navigation is "The process or activity of accurately ascertaining one's position and planning and following a route" and is derived from the root of the Latin verb navigare which is a combination of navis 'ship' and agere 'drive' in the early 16th century[1].

The history of navigation began nearly six thousand years ago when early humans first discovered floating objects they could stand on or use to travel across water. Archaeological and historical evidence suggests that early forms of water transportation were developed during the Neolithic period, when human communities began constructing simple watercraft from natural materials such as reeds, logs and wooden planks. One of the earliest known examples of watercraft is the dugout canoe discovered in the Netherlands, dated to approximately 6000 BC, which demonstrates that prehistoric societies had already developed basic techniques for travelling across rivers and coastal waters[2]. Similarly, archaeological findings from Mesopotamia and ancient Egypt indicate the use of reed boats and wooden vessels for transportation and trade along major river systems such as the Nile and the Euphrates. These early maritime practices gradually evolved into more sophisticated seafaring traditions and laid the foundations for the later development of systematic navigation techniques[3].

Over time, humans learned how to navigate on water, give directions and build boats from hardwoods. This marked the beginning of sailing and consequently, the development of navigation. As maritime activity expanded, particularly in the Mediterranean, the Indian Ocean and later the Atlantic, sailors increasingly relied on observational knowledge and practical instruments to determine direction and position. Different cultures developed various navigational tools to assist seafarers in locating their position at sea. For example, the kamal was used by Arab navigators in the Indian Ocean from the early medieval period to measure the altitude of Polaris in order to estimate latitude[4]. In Europe, instruments such as the cross staff and the quadrant became widely used during the late medieval and early modern periods for measuring the altitude of celestial bodies[5]. Similarly, devices such as the nocturnal and the astrolabe were developed to assist with astronomical observations and time determination, while the mariner's compass, which became widespread in Europe during the 13th century, provided a reliable method for identifying direction even when celestial bodies were not visible[6].

Navigation has never depended on a single instrument but rather on an integrated system of tools and knowledge developed across different maritime cultures. The fundamental requirements of navigation historically included determining direction, position, distance travelled and the safety of surrounding waters. In order to meet these needs, sailors relied on a combination of navigational instruments such as maps, compasses, astronomical devices and speed-measuring tools. These instruments did not emerge simultaneously but developed gradually across different maritime regions including the Mediterranean, the Red Sea, the Indian Ocean, the Chinese seas and the North Sea. Over centuries, technological knowledge circulated between these maritime zones, creating a shared navigational culture that shaped global seafaring traditions[7].

Among the most essential elements of navigation was cartography, since no navigational instrument could function effectively without spatial representation of the sea and coastlines. Consequently, maps,

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[1] Angus Stevenson – Christine A. Lindberg (eds.), *New Oxford American Dictionary*, Oxford University Press, Oxford 2010.
[2] Stefano Medas, *De Rebus Nauticis: L'arte della navigazione nel mondo antico*, L'Erma di Bretschneider, Roma, 2004.
[3] Denise Schmandt-Besserat, *Early Technologies*, Invited Lectures on the Middle East, Vol. III, Texas, 1979.
[4] Medas, 2004.
[5] P. Kenneth Seidelmann – Catherine Y. Hohenkerk, *The History of Celestial Navigation: Rise of the Royal Observatory and Nautical Almanacs*, Springer, Cham, 2020.
[6] Lois Ann Swanick, *An Analysis of Navigational Instruments in the Age of Exploration: 15th Century to Mid-17th Century*, Master's Thesis, Texas A&M University, Texas, 2005.
[7] George Fadlo Hourani, *Arab Seafaring in the Indian Ocean in Ancient and Early Medieval Times*, Princeton University Press, Princeton, 1995.

compasses, astronomical instruments and speed-measuring devices should be considered as components of a broader navigational system rather than isolated technological inventions. Portolan charts and other early nautical maps, which began to appear in the Mediterranean from the late thirteenth century onwards, illustrate how cartographic knowledge became closely integrated with practical navigation at sea[8].

This article will explore the historical evolution of navigational instruments, focusing on their innovations, applications and the broader significance of these developments in shaping maritime navigation. The study will specifically highlight the ship log which has played a crucial role in measuring speed and distinguishing itself from other navigational methods. The calculation of a ship's speed is central to this process as it enables the measurement of distance and time, utilizing technological advancements that have helped determine direction and enhance navigation. In particular, the study aims to demonstrate how the development of speed-measuring techniques contributed to the increasing accuracy of maritime navigation, especially during long-distance oceanic voyages when determining a vessel's progress became essential for safe and efficient travel.

1. Historical Navigational Instruments

Mathematics and astronomy were important factors in the development of navigational instruments. For a long time, astronomy was the only auxiliary science that could be used when a ship lost sight of land. However, in earlier historical periods navigation relied not only on mathematical calculations and astronomical observations but also on empirical environmental knowledge accumulated by seafarers over generations. Early sailors carefully observed natural indicators such as the movement of waves, prevailing winds, cloud formations and the behaviour of animals. Migratory birds, marine mammals and schools of fish were often interpreted as indicators of nearby land or seasonal routes, helping navigators maintain direction during long voyages.

In addition to these environmental cues, celestial bodies such as the sun, the moon and prominent stars played a central role in early navigation systems. The observation of the rising and setting positions of the sun, as well as the use of recognizable constellations and the pole star, enabled sailors to maintain approximate courses across open waters even before the development of specialized navigational instruments.[9] These observational practices formed the earliest foundations of maritime navigation and later influenced the development of more systematic astronomical instruments used for determining position at sea.

The development of navigational instruments followed the practical requirements of maritime travel. Early seafarers first relied on environmental observations such as winds, currents, stars and animal behaviour. As maritime travel expanded and voyages became longer, more systematic instruments were developed to determine direction, latitude, depth and speed. These developments did not occur in a single geographical region but emerged across various maritime cultures. Instruments and techniques used in the Mediterranean, the Indian Ocean and Northern European seas gradually influenced one another through trade, exploration and cultural exchange.

However, the development of navigational instruments should not be considered independently from the broader historical context of maritime navigation. Navigation at sea required a combination of practical knowledge, observational techniques and specialized instruments. Among the most essential elements for navigation were maps, astronomical instruments and directional devices such as the compass. The earliest examples of navigational practices and instruments appeared in regions with active maritime trade networks, particularly in the Red Sea, the Indian Ocean and East Asia. Historical studies indicate that Arab sailors, Chinese navigators and other maritime communities developed practical methods for determining direction, estimating distance and maintaining courses during long voyages. These early navigational traditions formed the foundation for later technological developments in maritime navigation.[10]

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[8] Tony Campbell, *"Portolan Charts from the Late Thirteenth Century to 1500" in The History of Cartography,* ed. John Brian Harley – David Woodward, University of Chicago Press, Chicago, 1987.

[9] Robert G. Bednarik, "The Beginnings of Maritime Travel", *Advances in Anthropology,* Vol. 4, No. 4, 2014, pp. 209–221.

[10] Hourani, 1995.

Early navigational techniques relied primarily on visual observations, environmental knowledge and simple tools. Over time, these techniques gradually evolved into more complex instruments that allowed sailors to determine latitude, direction and speed with increasing accuracy. The instruments discussed in this study represent different stages in this technological and scientific development.

By observing stars and planets and calculating the angles between them, the position of a ship in the middle of the ocean can be determined. Mathematics is the science of calculating latitude. Thanks to celestial bodies, our latitude can be calculated but longitude cannot be calculated without determining the time precisely[11]. This article focuses on historical instruments (see Figure 1) that use astronomical information for navigation and calculation of speed.

1.1. Cartography and the Development of Early Navigational Knowledge

One of the most fundamental requirements for navigation is the existence of maps. Cartography played a crucial role in maritime exploration because it allowed sailors to visualize coastlines, estimate distances and plan routes between ports. Cartography constituted one of the most fundamental elements of maritime navigation. Long before the development of sophisticated navigational instruments, sailors relied on coastal maps and sailing directions to travel between ports.

Early navigational maps were often based on accumulated empirical knowledge obtained through repeated voyages and oral traditions among sailors. Over time, this knowledge was recorded in written form and gradually transformed into more systematic cartographic representations.

During the medieval period, portolan charts became one of the most important cartographic tools used by Mediterranean sailors. These charts provided detailed information about coastlines, harbours and navigational hazards, allowing mariners to travel more safely between ports. Unlike earlier symbolic maps, portolan charts were highly practical documents designed specifically for navigation. They typically included compass roses and rhumb lines that helped sailors determine direction during voyages. Medieval portolan charts, which appeared in the Mediterranean during the 13th century, represented a significant advancement in maritime cartography. These charts provided detailed coastal outlines, ports and compass directions, allowing sailors to navigate with greater accuracy along known trade routes.[12]

The development of portolan charts illustrates how navigational knowledge was gradually systematized and transmitted through manuscripts and maritime journals used by sailors and pilots.

Cartographic knowledge was also preserved and transmitted through geographical treatises written by Arab scholars and travelers. These works contained valuable information about maritime routes, coastal geography and navigation techniques[13]. Together with astronomical instruments, maps formed one of the essential components of pre-modern navigation systems[14].

Although maps provided sailors with a spatial representation of coastlines and maritime routes, effective navigation required additional information about a vessel's movement at sea. Determining how far a ship had travelled over a given period of time was essential for estimating position when land was no longer visible. For this reason, navigators developed various techniques for estimating distance and speed during voyages, which eventually led to the development of instruments specifically designed to measure a ship's velocity through the water, such as the ship log.

1.2. Early Long-Distance Navigation: Viking Techniques and Northern European Traditions

The historical evolution of navigational instruments reflects a collective technological tradition rather than isolated discoveries. Maritime communities in the Mediterranean, the Red Sea, the Indian Ocean and Northern Europe contributed to the development of navigational knowledge. Through trade networks and exploration, these regional traditions gradually merged into a shared body of maritime

[11] Swanick, 2005.
[12] Campbell, 1987.
[13] Norman Joseph William Thrower, *Maps and Civilization: Cartography in Culture and Society*, University of Chicago Press, Chicago, 2007.
[14] Jerry Brotton, *A History of the World in Twelve Maps*, Penguin Books, London, 2012.

expertise[15]. Manuscripts, nautical manuals and ship journals preserved this knowledge and transmitted it across generations of sailors.

Long-distance navigation in the early medieval period was significantly advanced by the maritime activities of the Vikings. Between the 9th and 11th centuries, Viking sailors undertook extensive voyages across the North Atlantic, reaching regions such as Iceland, Greenland and even the coast of North America. These voyages required sophisticated navigational knowledge despite the absence of many later navigational instruments.

Historical sagas and archaeological evidence suggest that Viking navigators relied on a combination of environmental observation, solar orientation and primitive instruments[16]. One of the most discussed tools associated with Viking navigation is the so-called "sunstone". According to several historical interpretations, this crystal mineral could be used to locate the position of the sun even under cloudy conditions by detecting polarized light. This technique would have allowed navigators to determine direction when the sun was not directly visible[17].

Although the exact historical use of the sunstone is still debated among scholars, the concept illustrates the innovative observational methods employed by early seafarers. The navigational knowledge developed by Viking sailors later influenced maritime practices in Northern Europe and contributed to the gradual improvement of navigational techniques during the late medieval period. These developments eventually paved the way for the more advanced navigational instruments that became widely used during the Age of Exploration.

1.3. Kamal

Kamal is a type of navigational instrument invented by the Arabs for offshore navigation in the 9th century (see Figure 2). The principles of this device are based on the knowledge of Greek scientists and sailors of the late Roman Empire. Kamal was a simple but useful latitude measuring instrument used especially in the Arab world. It is known that it was used before, first by Arab traders in the 9th century, then in the Indian Ocean, and later by the Chinese. Kamal is a wooden rectangle measuring 5.0×2.5 cm with a hole in the middle through which a rope is passed and knotted at equal intervals. The knot at the end of the rope is placed in the mouth and adjusted back and forth on the rope with the piece of wood stretched over it until the upper position crosses the pole star and the lower position crosses the horizon. The latitude angle is determined by counting the nodes up to the point where the setting is held. If moving toward a known latitude, it is possible to calculate how much further distance needs to be travelled by connecting a specific node to a previously made measurement point at that latitude. If the angle is known, the distance between nodes is adjusted according to the angle. Before this, it is possible to position the first node relative to the second node. This system was a very useful method at that time. Observers were able to count the nodes by hand in the dark. For the measurements to be accurate and not affected by the shaking of the ship, the observers made their observations while sitting[18].

1.4. Cross Staff

The cross staff is a navigational instrument inspired by the kamal used by Arab sailors[19] (see Figure 3). In Europe, it is proven to be known since the 11th century[20]. The cross staff consists of a rectangular board, like a wedge, into which a marked ruler can be driven. The length of this ruler can vary between 90 and 100 cm. The purpose of this ruler is to cross its end between two objects from which the angle will be measured. The long part of the ruler is aligned at eye level and the angle is calculated by accepting the lower part of the rectangular plate as the horizontal line and the upper part as the observed celestial body. The meridian is calculated by taking the sun as a reference point during the day and the pole star as a reference point at night[21]. In addition to this, height of the pole star, the heights of other celestial

[15] Eva Germaine Rimington Taylor, *The Haven-Finding Art: A History of Navigation from Odysseus to Captain Cook,* Hollis and Carter, London, 1956.
[16] Gísli Sigurðsson, *The Viking World,* Routledge, London, 2013.
[17] Søren Thirslund, *Viking Navigation,* Viking Ship Museum, Roskilde, 2007.
[18] Medas, 2004.
[19] Swanick, 2005.
[20] Seidelmann – Hohenkerk, 2020.
[21] Swanick, 2005.

bodies and the angles between them can also be measured[22].

1.5. Quadrant

Quadrants are precision tools whose basic operation is like that of wedges and crossbars but are much easier to use (see Figure 4). A quadrant can measure angles of any celestial object. However, it cannot measure the angle between two celestial objects. The instrument is an angle gauge with a quadrant scale from 0 to 90 degrees. With this instrument, the angle indicated by the vertical line can be read by aiming at the desired star. The quadrant can also be used to determine latitude from the height of the pole star[23]. In Europe, the quadrant was first known in the 10th century when it was introduced by Arabs[24].

1.6. Dioptra

Dioptras date back to around 300 BC. They are devices consisting of a protractor, a rotatable optical tube or optical rod used to measure angles (see Figure 5). Combined with a planisphere, these two instruments became the first astrolabe, and various improved and advanced models of this instrument have been found until today[25]. The planisphere is an analogue calculator consisting of a star map on disks that can be adjusted to the month and time of the day. If the exact date and time is adjusted on the disk, the current constellation of the stars can be seen. For this, the planisphere is held to the sky while the middle of the disk is in the same position as the pole star[26]. The mathematical calculation of this system was first carried out by the Iranian scholar Abu Rayhan Al Biruni in the 11th century[27]. Based on the planisphere, the astrolabe was developed[28]. According to historical sources, astrolabes are more than 2000 years old. The first examples of astrolabes appeared in the classical Greek civilization and were navigational instruments prepared by astronomers to determine the positions of celestial bodies[29]. It is thought to have been developed in Alexandria in 150 BC but the principle of the astrolabe dates back to 250 BC. Theron of Alexandria wrote a scholarly book on the use of the astrolabe. It was stated that the astrolabe was used by Ptolemy to determine astronomical data recorded on the Tetrabiblos[30].

Since the types of the dioptra produced for use on land are quite sensitive to the shaking of ships at sea, simplified and more compact designs have been developed for use at sea. Models that could initially be used at certain latitudes and required interchangeable celestial rulers at different latitudes were replaced by universal types over time. As a result, the dioptra became an instrument that could show the exact position of particularly bright stars in the sky at a given date and time. The current star can be determined by aligning the moving parts to the desired date and time, or conversely, the date and time can be determined by adjusting the instrument according to the position of the star in the sky. In addition, dioptra allows us to measure the angle between us and the celestial body and to determine the position of the celestial body[31].

1.7. Nocturnal

A nocturnal is a type of a simple analogue device, first mentioned in the 13th century, that can determine the time of night using stars such as the pole star and constellations like the Little Dipper, Kochab and Cassiopeia. It consists of an outer disk that can be stacked and rotated, and a bookmark with a peephole in the middle (see Figure 6). In the northern hemisphere, the pole star is generally used. The outer disk of the night has a lunar ring divided in proportion to the length of the moon. The inner disk shows time divided into 24 parts. To measure time, assuming the date is known, the star reference point and the date line of Ursa Minor must intersect at our latitude. The pole star is then rotated until it passes through the central hole. At this point, the time is read from the point where the back of the marker

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[22] Osman Erkurt – Remzi Mehmet Fertan, "Antik Çağlardan Ortaçağa Navigasyon Yöntemleri ve Cihazlar", *15. Sualtı Bilim ve Teknoloji Toplantısı (SBT'2012)*, Istanbul 2012, pp. 59–75.
[23] Erkurt – Fertan, 2012, pp. 59–75.
[24] Seidelmann – Hohenkerk, 2020.
[25] Erkurt – Fertan, 2012, pp. 59–75.
[26] David W. Hughes – Carole Stott. "The Planisphere: A Brief Historical Review", *Journal of the British Astronomical Association*, Vol. 105, No. 1, 1995, pp. 35–39.
[27] Erkurt – Fertan, 2012, pp. 59–75.
[28] Hughes – Stott, 1995, pp. 35–39.
[29] Swanick, 2005.
[30] Schmandt-Besserat, 1979.
[31] Erkurt – Fertan, 2012, pp. 59–75.

intersects the inner disk. Since this device is based on celestial principles, it can determine time very accurately[32].

1.8. Mariner's Compass

Another important historical navigation instrument is the mariner's compass whose widespread use started in the 13th century. There are English sources, though, that describe a precursor of the compass about a hundred years earlier. It is described as a magnetic needle, sometimes within a straw, in a bowl of water. This needle adjusts itself to the North. About 1300, the compass was developed further. After that time, it became more common to fix the rotating needle over a compass rose with the cardinal directions[33].

2. Historical Means of Speed Calculation and Log Methods

Toward the end of 15th and the beginning of 16th century, the distance of travel and the speed of ships gained importance due to the start of the oceanic travel by the Portuguese and Spanish sailors. With the aim of discovering new lands to sail, such long distances were more dangerous than ever; therefore the distance, location and speed needed to be calculated. Especially with the aim of oceanic travel, speed gained more importance because sailors could not create accurate maps and calculations without knowing the speed. Other methods were not sufficient for long distance traveling since all they could rely on was observing the sky and making use of stars to calculate different longitudes and latitudes to travel[34].

However, the importance of speed calculation was not limited to Atlantic voyages alone. In the Mediterranean maritime tradition, particularly in the 16th century, the performance, balance and speed of galleys were also carefully observed and recorded, as these factors directly affected maneuverability, military efficiency and navigational planning. Contemporary sources indicate that Mediterranean sailors and naval commanders paid close attention to the relationship between vessel balance, rowing power and speed in order to maintain stability and operational effectiveness during voyages.[35]

It is possible to acknowledge from the logbooks that the sailors in those periods gave importance to the factor of speed. In maritime terminology, the term "journal" or "logbook" refers to the written navigational record kept aboard ships[36]. For example, as a famous one, Christopher Columbus' Journal (ship's logbook) of 1492, contains and discusses many measurements, statements and sometimes, even the speed is noted[37]. Two important methods of determining the speed of a ship, before exact measurements were possible, are described below.

2.1. Ship Log

Before the invention of the ship log method, sailors had been using a wooden log to guess their speed. The method was simple. One sailor heaving the wood log on the head of the ship as the others counted and made predictions based on their observation of what they could see without any measurement of time and length as the log passed the ship by. This method was called "heaving the log".

Archaeological evidence also demonstrates the early use of wooden maritime equipment. One of the oldest known examples of a wooden maritime artefact associated with ancient seafaring is exhibited today at the Bodrum Museum of Underwater Archaeology, where the remains from the famous Uluburun Shipwreck are displayed. The Uluburun shipwreck, dated to the 14th century BC, provides important archaeological evidence regarding early maritime technology and the use of wooden nautical

[32] Swanick, 2005.
[33] G. J. Marcus, "The Mariner's Compass: Its Influence upon Navigation in the Late Middle Ages", *Wiley*, Nos. 141/143, 1956, pp. 16–24.
[34] Geoffrey C. Gunn, *Overcoming Ptolemy: The Revelation of an Asian World Region*, Lexington Books, Lanham 2018.
[35] Mustafa Gürbüz Beydiz, *Akdeniz'de Kadırgalar ve Dengeler (XVI. yüzyıl)* in *Akdeniz Havzası Kültürel Çalışmalarından Seçmeler*, ed. Suna Timur Ağıldere, Atatürk Kültür Merkezi Başkanlığı Yayınları, Ankara 2024, pp. 179–224.
[36] Fahrettin Küçükşahin, *Ansiklopedik ve Teknik Denizcilik Sözlüğü*, Akademi Denizcilik Yayınları, İstanbul 2003, p. 581.
[37] Julius Emil Olson – Edward Gaylord Bourne, *Journal of the First Voyage of Columbus*, Wisconsin Historical Society, Wisconsin 2003.

materials in ancient navigation.[38]

Owing to its relevance and the fact that it is an easy material to find, they used wood logs but there were also many handicaps. Because the wood log is heavy and takes up a lot of space, it was only possible to have limited logs on the ships. Therefore after a short while, the sailors had been out of logs. Due to the lack of logs and environmental conditions at sea, the calculations and results were misleading. Over time, this process had developed and turned into the ship log method; a method of estimating a ship's speed through the water by tossing a line with a chip of wood attached overboard (see Figure 7) and counting the number of knots that pass through before the sandglass runs out. In the ship log method, there was a line with certain measurements to hold the log and after the calculations had been done, it was possible to pull the log back onto the ship and reuse multiple times. Additionally, this log was carved into a specific shape, which looked like a triangle with a circular end, that embedded a lead weight to balance it upright on the water for sailors to be able to see it. Sailors have been calculating speed for a long time by using a ship log but there were no accurate definitions or methods until it was first mentioned in William Bourne's print "A Regiment for the Sea" which was published in 1574. This print was the first occurrence of a ship log[39]. The origins of this method remain unclear, though it is attributed to the Portuguese Bartolomeu Crescencio in the late 15th century, where it was known as 'barquinha' or 'barca'[40], a small wooden device used in connection with a log-line to estimate a vessel's speed. The term derives from the Portuguese word for a small boat and should not be confused with large ocean-going vessels such as carracks that were used during the Age of Discovery[41]. Before such calculations of ship's speed were made, logs were similarly used to foresee the leeway. In other words, such similar methods were used for different aims, therefore the ship log has a long history. The definition of leeway can simply be interpreted as the drifting of a boat in a direction pushed and navigated by the wind through the water. To keep the direction of the ship stable, the sailors had been using a log to guess the leeway and observe the wake, which is the flow of the water caused by the motion of the boat as it creates waves on each side[42]. Sailors tied a line to the log and threw it overboard to observe and understand the direction the ship was heading toward. The log was dragged along in the waves along the axis of the wake. The method was slightly the same except the fact that heaving the log required a larger log, so it remains stable to the resistance of water. The purpose was to determine the speed by measuring the length of the line, which had run out after the sand glass was turned[43].

2.2. Dutchman's Log

Following the ship log, another method to measure a ship's speed was referred to at the beginning of the 17th century, in 1623, as the Dutchman's log, although it might have been used earlier. It is still uncertain why it was called the Dutchman's log, but it might be because it was popular amongst the Dutch. It is also not certain who invented it, but it was associated with Edmund Gunter as he had mentioned the rules in his work "De Sectore et Radio" which was published in 1623. He also described his mechanical device as Gunter's Rule, Gunter's Scale or simply Gunter, which sailors commonly used. It is a two-sided large scale showing natural lines and multiplied numbers based on the logs. This also was an important progress for the slide rule[44]. Apart from his contributions, he also explained under the headline "Containing such nautical questions, as are of ordinary vse, concerning longitude, latitude, rumb, and distance / To keep account of the ships way" the importance of the basic calculation of the log as in the following sentence "The way that the ship maketh, may be knowne to an old sea-man by experience, by others it may be found for some small portion of time, either by the log line, or by the distance of two knowne markes on the ships side."[45]. The process of the Dutchman's log is the sailor

[38] Cemal Pulak, "The Uluburun Shipwreck: An Overview", *International Journal of Nautical Archaeology*, Vol. 27, No. 3, 1998, pp. 188–224.
[39] Eva Germaine Rimington Taylor, *A Regiment for the Sea and Other Writings on Navigation*, Cambridge University Press, Cambridge 1963.
[40] Gunn, 2018.
[41] Anthony Turner, *Early Scientific Instruments: Europe 1400–1800*, Sotheby's Publications, London 1987.
[42] William Falconer, *An Universal Dictionary of the Marine*, David and Charles Reprints, Newton Abbot–London 1970.
[43] Ernst Crone, *How Did the Navigator Determine the Speed of His Ship and the Distance Run?*, University of Coimbra, Coimbra 1969.
[44] Charles H. Cotter, "Edmund Gunter (1581–1626)", *Journal of Navigation*, Vol. 34, No. 3, 1981, pp. 363–367.
[45] Edmund Gunter, *De Sectore & Radio: The Description and Use of the Sector and the Cross-Staffe*, William Iones, London 1624.

marking two places along the side of the ship and knowing the exact length between marked places. After determining the places and length, they throw a floating object and observe it until it passes the marked lines. During that, the time was counted to be able to calculate the speed later.

In the Dutchman's log method, small rectangular tobacco boxes, which have curved edges, were generally used and associated with Peter Holm, who designed a table chart to point out how speed was converted into time. This table chart is known as Zee Meteer which means Sea Measurer in English. Tobacco boxes were chosen as they can easily fit in pockets due to their usefulness, portability and measurements. Besides calculating the speed, it was also possible to know the day of the week. It was like a calendar divided into seven days which was sufficient to know even one of the days of the week (see Figure 8). To be able to calculate the speed easily, after checking the time while the floating object passed between two marked places, one could look at the timetable and find the value stated on the following column and figure out the calculated speed[46].

3. Results

This section presents a comparative analysis of navigational instruments and speed measurement methods in order to highlight their respective functions, similarities and differences within the context of marine navigation.

3.1. Comparison of the Navigational Instruments

Comparing the navigational instruments described in the previous chapters, it becomes clear that they have a broad range of different techniques and complexity. Some can be used only at nighttime while others can be used at any time. For some, it is necessary to have a deeper understanding of the functional principle whereas others can be applied with less knowledge.

The kamal is the only instrument where the traveling distance can be read off without any further calculations. In contrast to the kamal, the cross staff and the quadrant are easier to handle. Kamal also has the advantage of not depending on the pole star because the sun is a suitable reference point as well. Therefore, they can be used at daytime and at night. With the quadrant, one can determine latitude by measuring the altitude of the pole star whereas the cross staff provides information about the meridian and angles between celestial bodies. When it comes to accuracy, the quadrant is superior to kamal and cross staff [47].

Because all these methods rely on fixed celestial reference points, they can only be used in clear or mostly clear skies. Due to necessity of a fixed point, another possible source of inaccuracy is rough seas. In contrast to the kamal, cross staff and quadrant, the dioptra and the nocturnal contain a map of the stars. With the aid of the map, apart from the altitude of celestial bodies, the time can be determined and be connected to their rising and setting, too. Compared to the three instruments mentioned previously, these two can be considered highly advanced navigational devices. Yet, there is one constraint. The time they indicate is just a rough approximation. Therefore, it is not possible to determine the longitude sufficiently with them[48].

The dioptra and the nocturnal are much more complex which means they require more knowledge to be applied correctly. While the dioptra does not only function with stars but also with the sun and other celestial bodies, it works at day and night. Contrary to that, the nocturnal is an instrument for night time use only. For both devices, it is necessary to know the exact date: An information that is irrelevant, if the kamal, cross staff or quadrant is employed. In comparison to celestial navigational instruments, the mariner's compass has the advantage to work at every time of the day or night without needing any additional information. It is also easy to understand and read. Yet, the information it provides is limited to the cardinal directions. It cannot determine the position on the latitude or the time. Since the compass does not need a fixed reference point to be aimed at, it is more suitable in case of rough sea. But due to its magnetic features, it is prone to manipulation by other magnetic objects.

[46] Ernst Crone, *Pieter Holm and His Tobacco Box*, Marine Historical Association, 1953.
[47] Dava Sobel, *Längengrad*, Berlin Verlag, Berlin 2010.
[48] Adrienne Lois Kaeppler – Nigel Rigby (eds.), *James Cook and the Discovery of the South Seas*, Verlag Neue Zürcher Zeitung, Zurich 2010.

3.2. Comparison of the Ship Log and the Dutchman's Log Methods

There is one great difference between the ship log and the Dutchman's log: In the Dutchman's log method, the time already had been counted as the object passed the marked points on the ship's side. These points had been determined previously and were known by the sailors. On the other hand, in the ship log method, there was a particular time in which the line of the log had ran out. Both methods had different constant and variable values. In this matter, the distance is constant in the Dutchman's log and the time is variable, whereas time is constant in the ship log method and the distance is variable. As a result, the speed can be calculated in both methods[49].

Conclusion

The evolution of navigational instruments has played a pivotal role in the advancement of seafaring, enabling explorers, merchants and sailors to traverse vast and unpredictable oceans with increasing accuracy and confidence. From the early days of floating logs to the sophisticated celestial and mechanical instruments developed over centuries, each innovation represented a crucial step toward safer and more efficient maritime travel.

The reliance on celestial navigation, as seen with instruments such as the kamal, cross staff, quadrant and dioptra highlights the ingenuity of early navigators in utilizing astronomy and mathematics to determine their position. While these tools allowed for rudimentary latitude calculations, their limitations such as dependency on clear skies and precise user knowledge necessitated further advancements. The introduction of the mariner's compass marked a significant breakthrough allowing navigation to continue in poor visibility conditions and reducing reliance on celestial bodies alone.

However, beyond determining direction, accurately measuring a ship's speed was equally crucial in maritime exploration. The ability to calculate speed enabled navigators to estimate distances traveled, improving their ability to chart routes, manage provisions and ensure timely arrivals. The ship log and Dutchman's log played a fundamental role in this process. The ship log, by utilizing a weighted log and marked line, provided a reusable method for estimating speed while the Dutchman's log introduced an alternative approach that relied on timing floating objects passing between fixed points. These methods provided early sailors with practical means to estimate their progress at sea, forming the basis for more sophisticated speed calculation techniques. These developments were crucial for long-distance oceanic travel, particularly during the Age of Discovery, which began in the early 15th century and lasted through the 17th century, when accurate navigation determined the success of voyages, trade routes and territorial expansion.

Beyond their technical importance, navigational instruments also had profound socio-economic consequences. Improvements in navigation enabled maritime societies to expand their geographic horizons, establish new trade networks and maintain long-distance communication between distant regions. Early seafaring communities such as the Vikings demonstrated how navigational knowledge could facilitate exploration and territorial expansion. Viking voyages across the North Atlantic during the early medieval period led to the settlement of regions such as Iceland and Greenland and even temporary contact with the North American continent. These expeditions illustrate how navigational knowledge and practical techniques played a crucial role in shaping early maritime mobility and intercultural interaction.

Similarly, the progressive refinement of navigational instruments during the late medieval period created the technological conditions necessary for the Age of Discovery. Instruments such as the compass, astrolabe and later speed-measuring devices allowed European navigators to undertake longer and more systematic oceanic voyages. These developments facilitated the establishment of new maritime trade routes between Europe, Africa, Asia and the Americas. As a result, navigation became not only a technical practice but also a driving force behind economic expansion, cultural exchange and geopolitical transformation in the early modern world.

The ongoing refinement of navigational instruments laid the foundation for modern technology,

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[49] David Watkin Waters, *The Art of Navigation in England in Elizabethan and Early Stuart Times*, Hollis and Carter, London 1958.

including GPS and satellite navigation, which have revolutionized maritime travel. The historical progression of these tools underscores the importance of precision and reliability in navigation, demonstrating how human ingenuity and scientific advancements have continuously shaped the course of exploration and global connectivity.

Ultimately, the historical development of navigational instruments reflects the broader relationship between scientific knowledge, technological innovation and maritime activity. The gradual improvement of navigational tools did not merely enhance the technical capabilities of sailors; it also contributed to the expansion of global trade, the circulation of knowledge and the emergence of interconnected maritime worlds.

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APPENDIX

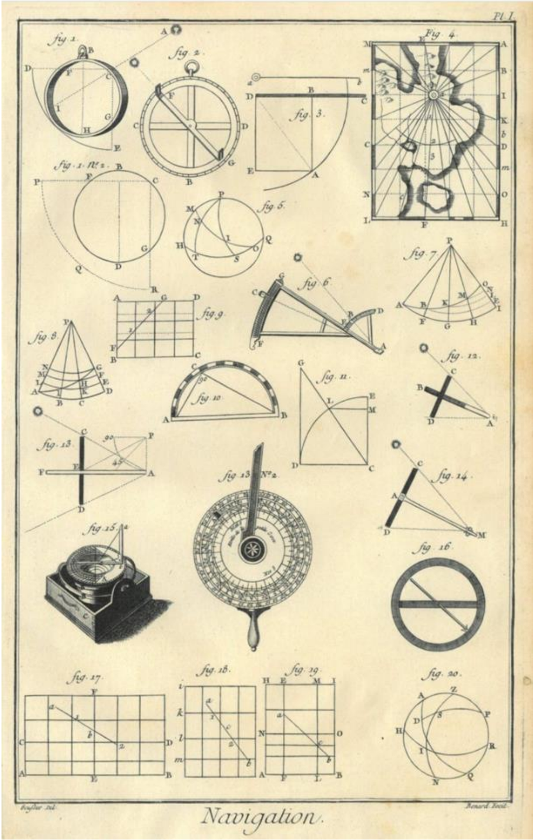

Figure 1: Navigational instruments[50].

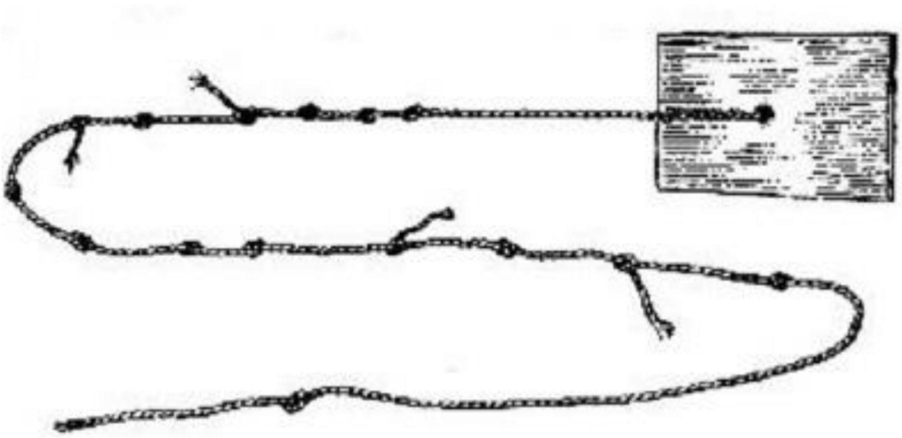

Figure 2: Kamal[51].

[50] Denis Diderot – Jean Le Rond d'Alembert, *Recueil de Planches, sur les Sciences, les Arts Libéraux, et les Arts Méchaniques: avec Leur Explication*, Briasson, Paris 1763.
[51] Medas, 2004.

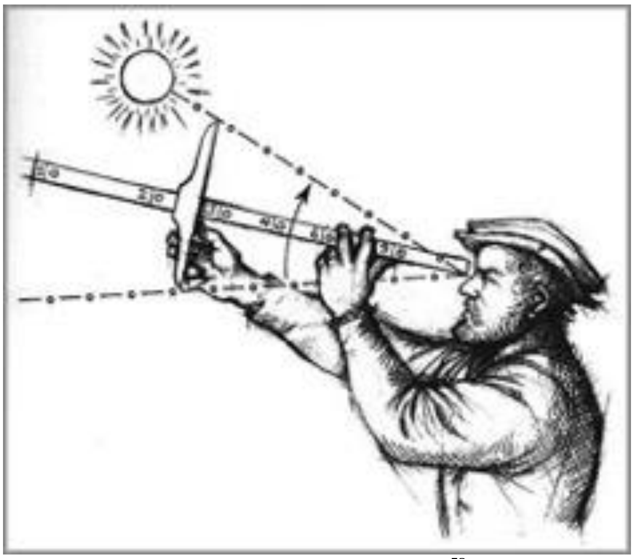

Figure 3: Use of a cross staff [52].

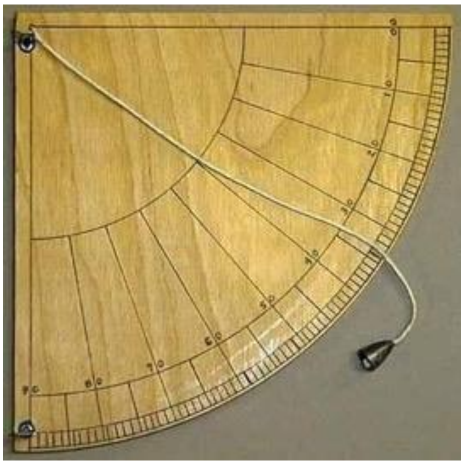

Figure 4: Quadrant[53].

[52] Medas, 2004.
[53] Erkurt – Fertan, 2012, pp. 59–75.

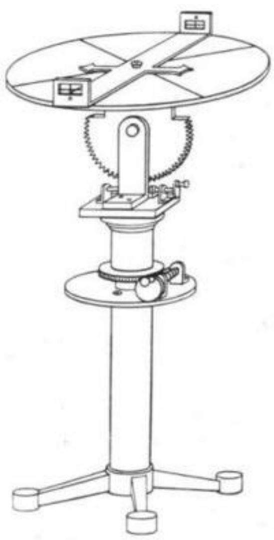

Figure 5: Dioptra[54].

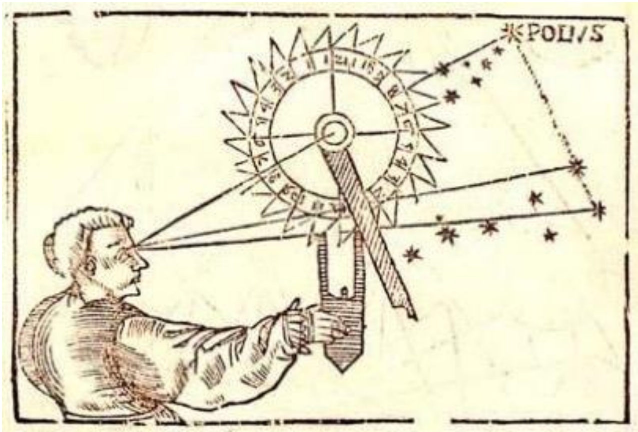

Figure 6: Use of a nocturnal[55].

Figure 7: A ship log[56].

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[54] Michael Jonathan Taunton Lewis, *Greek and Roman Surveying and Surveying Instruments*, University of Chicago Press, Chicago 2012.
[55] Medas, 2004.
[56] Museo Civico Navale di Carmagnola, *Solcometro a Barchetta*, photograph, Turin 2025.

Figure 8: The so-called Holm box shows the perpetual calendar on one side and a table on the other to calculate the speed of the ship[57].

[57] Pieter Holm, *Nautical Box from Holm*, tobacco box, Pijpenkabinet Collections, Amsterdam 1729.