# Part I

# History and applications

# 1 Positioning through the ages

For thousands of years, the ability to explore the world has significantly impacted human civilization. Human explorations have enabled the interaction of cultures for the purposes of geographic expansion (for example, through war and colonization) and economic development through trade. These interactions have also played a pivotal role in an exchange of knowledge that has supported the advancement of science, the development of religion, and the flourishing of the arts throughout the world.

World exploration is largely enabled by the ability to control the movement of a vessel from one position to another. This process, known as navigation, requires the knowledge of the locations of the source and destination points. The process of determining the location of points in space is known as positioning. In this book, we use the terms location and position interchangeably to refer to the point in physical space occupied by a person or object.

Throughout history, various positioning methods have been developed including methods using the relation of a point to various reference points such as celestial bodies and the Earth's magnetic pole. More recently, the advent of wireless communications has led to the development of a number of additional positioning systems that enable not only navigation, but also the delivery of additional value-added services. The focus of this book is one such positioning method that employs wireless local area signals to determine the location of wireless devices.

In this chapter, we provide a brief account of the historical development of navigational techniques (Section 1.1). As shown in Figure 1.1, we consider two distinct periods. The first period, termed the Age of Traditional Navigation, refers to the development of navigational techniques developed to facilitate exploration and sea travel before the nineteenth century (Sections 1.2 and 1.3). The second period, termed the Age of Modern Navigation, begins with the advent of wireless communication, which ultimately gave rise to the positioning systems in commercial use today (Section 1.4).

## 1.1 Origins of navigation

The development of navigational science was necessitated by the human need to roam about the world. In ancient times, travel played an important role not only in exploration, but also in trade, conquest, and religious and cultural expansions. For example, colonization and the spread and development of the major religions of the world were made possible because of the human ability to move between distant locations. Much of

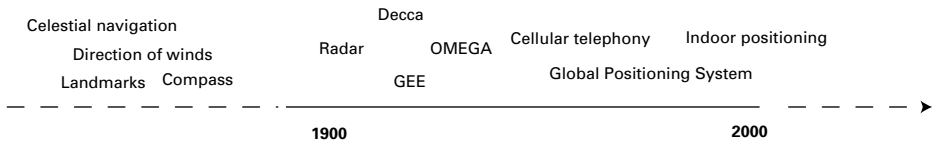


**Figure 1.1.** Overview of the history of navigation.

the world remained unexplored and unmapped during ancient times. As such, effective positioning and wayfinding techniques were needed to guide travel between two points. Clearly, navigation requires knowledge of one's position as one travels along the path connecting the source and destination of travel.

Ancient civilization traveled by land and sea. At this time, navigation was made possible through the use of known landmarks to position oneself. The landmark-based mode of wayfinding was sufficient at the time when sea travel was used primarily for hunting and fishing. However, as time passed, the potential of sea travel for exploration was unlocked. Such exploration necessitated long-haul voyages that required sea vessels to travel great distances from the shoreline. This rendered the landmark-based mode of navigation insufficient, and motivated the development of more advanced positioning and navigation techniques [74].

## 1.2 The age of traditional navigation

Ancient navigational techniques generally obtained one's location relevant to reference points with known positions. In this section, we briefly review some of these techniques.

### 1.2.1 Navigation based on landmarks

As mentioned previously, known landmarks, such as the shoreline, were used to localize to determine the course of travel of vessels. In the case of sea travel, ships and boats used the shoreline as a reference for wayfinding during the day. For night travel, lighthouses were built to guide travelers along the coast. One of the seven wonders of the ancient world, the Pharos of Alexandria, is an example of such a lighthouse built in Egypt around 200 years before Christ.

In addition to the above methods, other modes of navigation in the ancient world employed techniques that relied on observing the direction of winds and sea currents to determine the direction of travel of vessels.

### 1.2.2 Celestial navigation

Ancient civilizations such as the Phoenicians, Greeks, Persians, Polynesians, Vikings, and the Chinese commonly used on a navigational technique known as *celestial navigation*. This technique employs celestial bodies, including the sun, the moon, and various navigational stars, as references for positioning. Crude modes of celestial positioning

have been used for thousands of years. For example, in Homer's epic work, the *Odyssey* (dating back to approximately 1000 years before Christ), the hero Odysseus uses the Great Bear constellation to navigate.

Celestial navigation uses angular measurements between these celestial bodies and the horizon to obtain one's position. This required the development of instruments for measuring angular distances from the horizon. An example of such an instrument is the *astrolabe*. The invention of this instrument is attributed to the Greek astrologer and mathematician Hipparchos in the second century before Christ [74].

Celestial navigational techniques in the ancient world were crude and imprecise. These basic techniques were further refined and perfected over several centuries and led to the development of precise maritime navigation as we shall see in later sections. In fact, the basic ideas of the ancient world underlie many of the positioning systems used today [74].

### 1.2.3 The compass

Compass-based navigation is based on the use of the earth's magnetic pole as a reference. A compass consists of a magnetized needle that aligns itself with the earth's magnetic pole. As such, this device can be used to determine the heading or direction of vessels. Figure 1.2 shows an example of a modern compass. Though the origins of the compass date back several thousand years, the first reference to the use of this device for navigation is found in the twelfth century [74].


**Figure 1.2.** Example of a modern compass. Image © iStockphoto.com/Ldf.

## 1.3 The age of exploration

As time passed, the aforementioned techniques were perfected to allow for long-distance travel both by land and sea. For example, the Middle Ages saw significant advancement in the science of navigation by Islamic and Persian scholars who improved measurement techniques used in celestial navigation and created detailed maps of the known world. For example, Islamic navigators invented the *kamal*, an instrument used for measuring the angle between the horizon and a navigational star and further improved existing navigational instruments such as the astrolabe. Figure 1.3 shows a photograph of a Persian astrolabe from the thirteenth century. The scholars of this period also contributed significantly to the development of cartography (map making) and geographical sciences.

Given this backdrop, the Age of Exploration began in the fifteenth century when European ships set out to conquer and explore new lands. It was during the Age of Exploration that Portuguese and Spanish explorers including Christopher Columbus (fifteenth century), provided accounts from distant lands that led to the interaction of

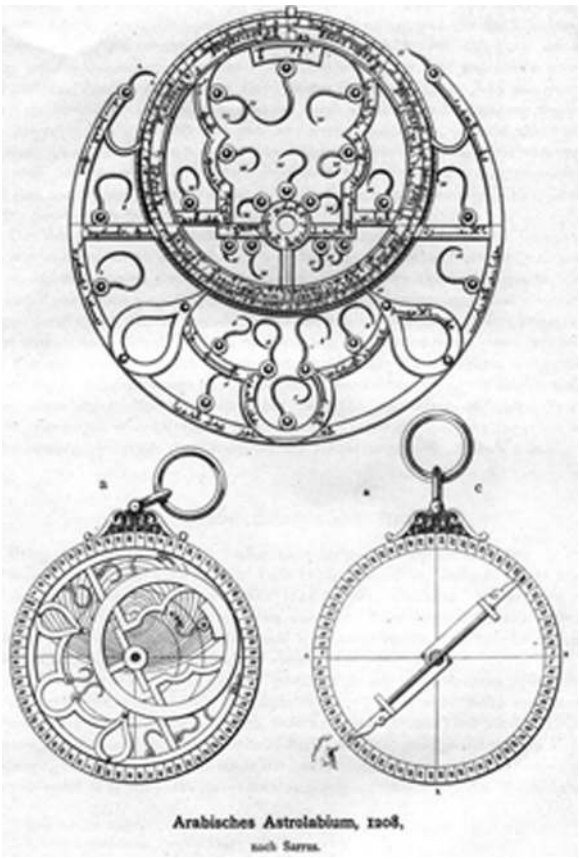


**Figure 1.3.** A Persian astrolabe from the thirteenth century. "Astrolabe," Wikipedia, The Free Encyclopedia, http://en.wikipedia.org/wiki/Astrolabe.

**Figure 1.4.** A German astrolabe from the sixteenth century. "Astrolabe," Wikipedia, The Free Encyclopedia, http://en.wikipedia.org/wiki/Astrolabe.

the Old and New Worlds. The subsequent two centuries marked a significant milestone in the development of systematic methods for navigation that enabled long-haul travel between the continents. During this time, traditional navigational charts and instruments were further refined (see, for example, a German astrolabe from the sixteenth century in Figure 1.4).

By this time, a well-established coordinate system was in use that represented the position of each point on earth using two pieces of information, namely *latitude* and *longitude*. Figure 1.5 depicts this coordinate system.

Latitude is the angular distance north or south of the equator (the equator has a longitude of 0 degrees, whereas the north and south poles have latitudes of 90 degrees north and south, respectively). Latitude was obtained using instruments such as the astrolabe which allowed the measurement of the angular distance between two objects. Near the end of the seventeenth century, Sir Isaac Newton invented the quadrant, used for the measurement of angular distances between two objects. This paved the way for the development of the octant and, consequently, the sextant, further perfecting the measurement of latitude. Figures 1.6 and 1.7 show examples of these instruments.

Longitude is the angular distance between a point's meridian and the Prime Meridian. One way to compute longitude involves calculating the time difference between one's position and a fixed point (because the earth rotates 15 degrees in one hour, knowledge of the time difference between the two points provides an angular distance). As such, measurement of longitude requires precise knowledge of time. However, since this knowledge was not available to early navigators, they had to rely on methods such as dead reckoning to find their longitude. This led to inaccurate navigation, which resulted in prolonged voyages and misdirected ships. Tragically, errors in computation of longitude caused the Scilly naval disaster of 1707 when almost 2000 lives were lost.

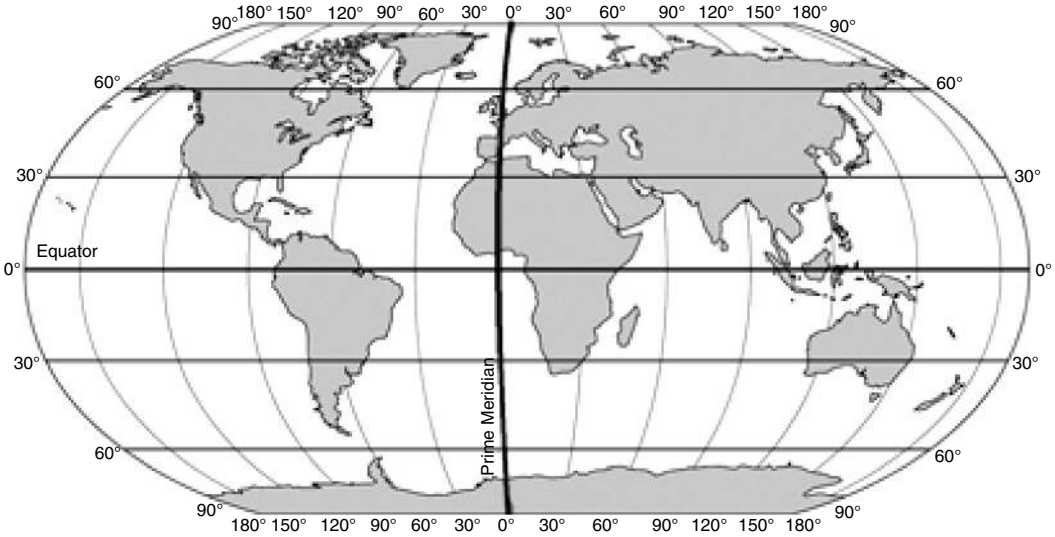


**Figure 1.5.** Latitude and longitude lines. Horizontal and vertical lines correspond to latitude and longitude lines, respectively.

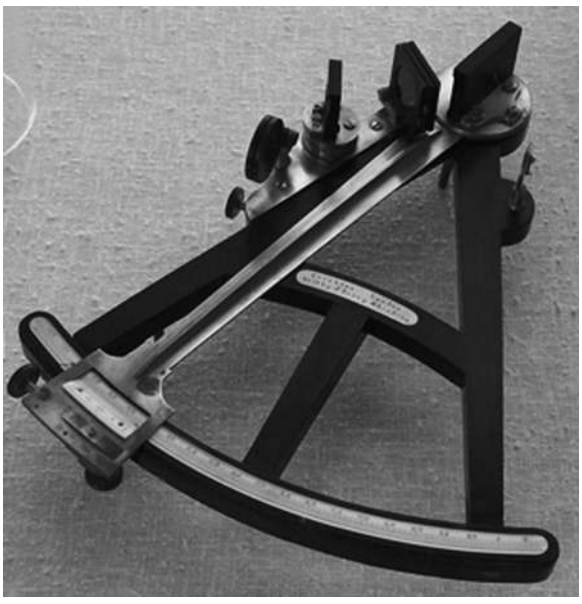

**Figure 1.6.** An octant. "Octant", Wikipedia, The Free Encylopedia, http://en.wikipedia.org/wiki/Octant.

This problem of longitude was so significant to navigators of the seventeenth and eighteenth centuries that several organizations, including the British, French, and Spanish governments, offered prizes for finding the solution to the longitude problem. This led to the development of the marine chronometer, initially proposed by John Harrison. This

**Figure 1.7.** A sextant. Image © iStockphoto.com/DNY59.

**Figure 1.8.** John Harrison's marine chronometer. "Marine chronometer," Wikipedia, The Free Encyclopedia, http://en.wikipedia.org/wiki/Marine_chronometer.

chronometer is shown in Figure 1.8. The device allowed for precise measurement of time at a fixed location, which in turn enabled sailors to measure longitude given the local time.

The eighteenth and nineteenth centuries further saw the refinement of tools used for measurement of latitude and longitude. These remained the primary modes of navigation until the dawn of modern navigation in the twentieth century.

## 1.4 The age of modern navigation

### 1.4.1 Radio-based systems

The advent of wireless communications in the late nineteenth century marked another important step in the development of positioning and navigation systems. On December 12, 1901, Guglielmo Marconi (pictured in Figure 1.9) successfully accomplished the first transatlantic wireless transmission – the Morse code "S" was sent from Cornwall, England, to Newfoundland, Canada. Marconi also demonstrated the potential of wireless telegraphy for communication between ships and shore. These wireless communication systems were initially used in sea navigation to request information, assistance, or to transmit warning messages.

As we shall see in later chapters, wireless signals offered two ways for improving positioning systems [74]. First, these signals could serve as landmarks. Second, wireless signals could be used to derive timing information to obtain distances from known positions.

The first wireless positioning system was developed in the early twentieth century. This system, known as the Radio Direction Finder, relied on signals received from a radio transmitter with a known location. A landmark-based technique was employed whereby a directional antenna was used to find the direction of incoming radio signals, and hence that of the known landmark.

**Figure 1.9.** Guglielmo Marconi. "Marconi," Wikipedia, The Free Encyclopedia, http://en.wikipedia.org/wiki/Marconi.

In the early twentieth century, the first prototypes of the RAdio Detection And Ranging (radar) system were developed. The radar system transmits pulses of radio waves and measures the reflected waves to determine the altitude, bearing, range, and speed of objects. Subsequently, several other radio-based positioning systems were developed including the GEE, LOng RAnge Navigation (LORAN), OMEGA, and Decca systems. These systems belong to the class of hyperbolic positioning systems which use the time difference between the arrival of radio signals from two transmitters to compute the location of a receiver (further details on this method are provided in Chapter 3).

Another important development in recent years is cellular telephony. The primary application of cellular systems is mobile communication. However, in 1996, the United States Federal Communications Commission introduced the E-911 mandate which requires mobile operators to know the position of their users within prescribed limits. This led to the development of cellular-based positioning systems.

### 1.4.2 Satellite-based systems

In 1951, the first artificial satellite, Sputnik, was launched into the earth's orbit. The success of Sputnik precipitated the space race which in turn led to significant advances in space travel. Though the intended application for artificial satellites was not positioning, it was soon realized that the position of a satellite could be accurately determined by observing its transmissions. The promise of this technique led to the development of satellite-based positioning systems in the late twentieth century, most notably the Global Positioning System (GPS), which was made available for civilian use in the 1990s. This system is explained in detail in Chapter 3.

The development of satellite-based positioning systems, together with the advent of mobile computing, have allowed mass market, commercial use of positioning information in a new generation of applications known as location-based services. These services have revolutionized the way we consume positioning information. Chapter 2 is dedicated to a detailed discussion of these services.

## 1.5 Chapter summary

The need for location information is a direct result of the human need for exploration, trade, and conquest. The origins of navigational sciences date back to thousands of years before Christ. Until the nineteenth century, location information was obtained mainly by employing celestial bodies as reference points. This changed with the advent of wireless communication, which allowed propagation properties of wireless signals to be exploited to obtain location information. A prominent example of wireless positioning systems is the Global Positioning System (GPS), which employs artificial satellites as reference points for positioning. The tremendous success of the GPS system in civilian applications, together with the maturation of mobile computing, have kindled a new era in the history of positioning systems and the dawn of a revolution in the way location information is generated and consumed.