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A Little Piece of History …

Abstract

In this chapter, we briefly look back at the evolution of geographical positioning. Our intention is to show that indoor positioning is indeed a very recent need that has come about due to the spread of modern mobile-connected terminals and owners wanting to receive numerous so-called services, many of which are greatly enhanced when associated with the user location. The benefit of many of them is 10-fold when associated with the user location. Thanks to the Global Positioning System, the famous GPS, this association was made possible in the early 1990s. Unfortunately, this fantastic system has been unable to meet the performance required indoors, where a "typical" urban citizen spends the majority of his or her time (*The term "typical" will appear sometimes in the book. Although experience has shown such "typical" persons, objects, or environments do not exist, we will use this term to appoint a classical situation*).

Keywords *History; longitude problem; navigation; clocks; Harrison*

As soon as human beings decided to explore new territories, or even just to move within new territories, they needed a way to locate themselves in their environment.

1.1 The First Age of Navigation

The origins of navigation are as old as man himself. The oldest traces have been found in Neolithic deposits and in Sumerian tombs, dating back to around 4000 years CE The story of navigation is strongly related to the history of instruments, although they did not have a rapid development until the invention of the maritime clock, thanks to John and James Harrison, in the eighteenth century. The first reason that pushed people to "take to the sea" is probably related to both the quest for discovery and the necessity of developing commercial

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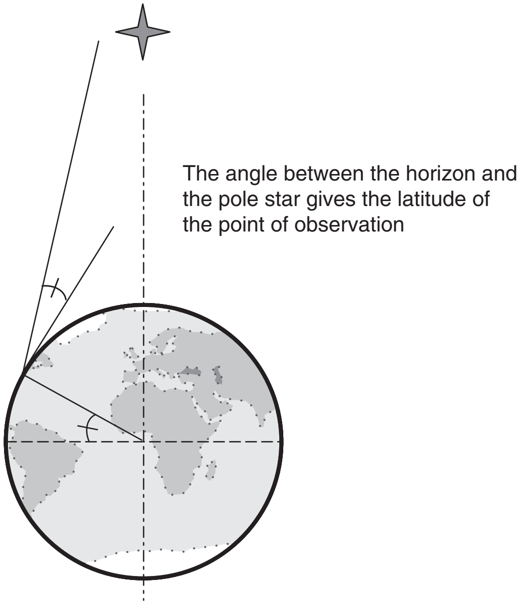

Figure 1.1 Determining latitude with the pole star.

activities. In the beginning, navigation was carried out without instruments and was limited to "keeping the coast in view." It is likely that numerous adventurers lost their lives by trying to approach what was "over the horizon."

The astronomical process used for positioning was quite inaccurate, and hence, frequent readjustments were required. The localization was even more complex because of the lack of maps. Nowadays, the situation of indoor positioning is in the same state: accuracy is not at the desired level, and frequent readjustments are needed. Moreover, one of the most important problems is the lack of indoor maps allowing navigation (i.e. not just an image). This very hot topic is dealt with in Chapter 13.

Unfortunately, astronomical positioning was only able to give the latitude of the point, as can be understood from Figure 1.1. The longitude problem would remain unresolved for centuries: will it be the same for indoor positioning?[1]

A first remark can be made at this stage: positioning at the epoch was not continuous in time and space, contrary to what we are looking for today. However, is it really essential indoors?

1.2 Longitude Problem and Importance of Time

The so-called longitude problem was much more difficult to solve and took almost three centuries. During this period, significant progress occurred

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[1] In fact, technological solutions already exist, but this is the combination of the perceived constraints that the solution should address, which is too stringent for current technologies.

concerning instruments and maps, but nothing for determining the longitude. As early as 1598, Philipp II of Spain offered a prize to whoever might find the solution. In 1666, in France, Colbert founded the "Académie des Sciences" and built the Observatory of Paris: one of his first goals was to find a method to determine longitude. King Charles II also founded the British Royal Observatory in 1675 in Greenwich to solve this problem of finding the longitude at sea. Giovanni Domenica Cassini, a professor of astronomy in Bologna, Italy, was the first director of the French academy and in 1668 proposed a method of finding the longitude based on the observations of the moons of Jupiter: this work followed the observations made by Galileo[2] concerning these moons using an astronomical telescope. It had been known from the beginning of the sixteenth century that the time of the observation of a physical phenomenon could be linked to the location of the observation; thus, knowing the local time where the observations were made compared to the time of the original observation (carried out at a reference location) could give the longitude. Cassini established this fact with the moons of Jupiter after having calculated very accurate ephemeris. Unfortunately, this approach needs the use of a telescope and is not practically applicable at sea.

On 11 June 1714, Sir Isaac Newton confirmed that Cassini's solution was not applicable at sea and that the availability of a transportable timekeeper would be of great interest. It has to be noticed that Gemma Frisius also mentioned this around 1550, but it was probably too early. On 8 July 1714, Queen Anne offered, by Act of Parliament, a £20 000 prize[3] to whoever could provide longitude to within half a degree. The solution had to be tested in real conditions during a return trip to India (or equivalent), and the accuracy, practicability, and usefulness had to be evaluated. Depending on the success of the corresponding results, a smaller part of the prize would be awarded.

The development of such a maritime timekeeper took decades to be achieved but finally had an impact on far more than navigation. The history of Harrison's clocks is quite interesting, and time is really the fundamental of modern satellite navigation capabilities. We have seen that Isaac Newton himself confirmed that the availability of a transportable maritime clock would be the solution to the longitude problem: the realization of such a clock, however, was not so easy. The main reason is that the clock industry was fundamentally based on physical principles dependent on gravitation (the pendulum). This was acceptable for terrestrial needs, but of no help in keeping time when sailing. Thus, a new system had to be found.

The reason that time is of such importance is because of the Earth's motion around its axis. As the Earth makes a complete rotation in 24 hours, it means that every hour corresponds to an eastward rotation of 15°. Thus, let us suppose that one knows a reference configuration of stars (or the position of the sun or the moon) at a given time and for a given well-known location (e.g. Greenwich). If you stay at the same latitude, then you will be able to observe the same

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[2] Hence, the name of the European GNSS.

[3] This amount is equivalent to more than $15 million today.

configuration but at another time (later if you are eastward and earlier if westward): the difference in times directly gives the longitude, as long as the time of the reference location (Greenwich in the present example) has been kept. The longitude is simply obtained by multiplying this difference by 15° per hour, eastward or westward. The method is very simple and the major difficulty is to "keep" the time of the reference place with a good enough accuracy, i.e. with a drift less than a few seconds per day. Pendulums, although of good accuracy on land, were unable to provide this accuracy at sea, mainly because of the motions of the ship and changes in humidity and temperature.

John Harrison built four different clocks, leading to numerous innovative concepts. After almost 50 years of remarkable achievements (August 1765), a panel of six experts gathered at Harrison's house in London and examined the final "H4" watch. John and William (his son) finally received the first half of the longitude prize. The other half was finally awarded to them by the Act of Parliament in June 1773. Certainly more important is the fact that John Harrison was finally recognized as being the man who solved the longitude problem.

One of the most famous demonstrations of Harrison's clocks' efficiency was given by James Cook during the second of his three famous voyages in the Pacific Ocean. This second trip was dedicated to the exploration of Antarctica. In April 1772, he sailed south with two ships: the *Resolution* and the *Adventure*. He spent 171 days sailing through the ice of the Antarctic and decided to sail back to the Pacific islands. He returned to London harbor in June 1775, after more than 40 000 nautical miles. During this voyage, he was carrying K1, Kendall's copy of Harrison's H4. The daily rate of loss of K1 never exceeded eight seconds (corresponding to a distance of two nautical miles at the equator) during the entire voyage: this was the proof that longitude could be measured from a watch.

Indoor positioning is almost in the same situation as that of the longitude determination in the early eighteenth century: it seems to be quite close, but there is indeed no satisfactory solution. Hopefully, it will take less than 50 years to find an acceptable approach.

1.3 Link Between Time and Space

The perception of time has changed quite a lot over the centuries until the current omnipresent availability of a precise time that can thus be shared by everybody. By briefly analyzing the evolution of the effects of this availability of time on people's life, some parallels are drawn concerning possible changes induced by the availability of positioning.

1.3.1 A Brief History of the Evolution of the Perception of Time

At the very beginning, time and space were notions that people felt: the number of days of walk needed to reach a given place and drawing simple maps of places. This was achieved long before writing was available.

With the augmentation of the diversity of his activities, human being has increased both his living space and the need to measure time in order to better organize commercial activities, for example. The lunar calendar appeared to help in this task: the observation of the phases of the moon was enough to give a date. Unfortunately, this was limited to activities such as agriculture, which relies more on annual cycles. Then, solar calendars appeared that allowed the collective organization of the activities of the society. The notion of year and months was already present. Furthermore, it was quite precise for seasonal activities. Further improvements were rapidly required in order to divide the day into time units to organize the activities within a given day. The initial approaches were based on the sundial, but the obvious problem is that the duration of a unit of time is not the same in every season: thus, a daytime unit lasted longer in summer than in winter. Ingenious water clocks (clepsydras) were imagined to solve this problem: in addition, this made the time available at night. Time became available: the next steps were to make it both transportable and synchronized from place to place.

The monks were the first to develop "clocks" in order to synchronize their religious practices. The first achievements were based on rings and gongs. Here, the interesting point is the fact that it allowed for synchronization for a whole group of people (those that heard the bells): knowing the precise time is absolutely not required.[4] Universal time was nevertheless not yet a worry as life revolved around local affairs. Furthermore, the night remained "another world," but it was acceptable to use the Sun for time. The evolution was, however, to develop clocks that were able to "ring" at various times of the day, even without a dial and hands. The most advanced such clocks were also able to ring at night in order to organize the whole life of the village.

The next step in the management of time measurement and restitution was the advent of mechanical dials that allowed people to "locate" themselves within the day. Representations are used (often based on religious or astronomical symbols) in such a way that even those that did not read were able to understand the time. All the mechanisms used at that time were based on gravitational effects meaning that it was not possible to use them at sea (this leads us back to the beginning of the chapter).

Meanwhile, Western countries started to expand around the world where difficulties appeared for commercial activities and synchronization. The first trains are in operations, but clocks are still synchronized on the Sun midday and time drifts are "visible." Trains raised the need for a coordinated universal time, and this was the starting point for time zones.

The industrial revolutions brought about a change in attitudes toward time: the work was no longer related to the task, but to a given amount of time, new relationships were created between employers and employees, and new claims arose concerning the rights of workers who sometimes organized strikes in

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[4] Note that this notion could be interesting in the case of positioning: there is no permanent need for knowing precise positioning, as long as it is possible to know the path to be followed and maybe the time it will take to reach the next stopping place.

support of their claims. Industry realized that "time is money" and life itself became defined in relation to time. In addition, time became a global notion, shared worldwide. This globalization raised the (paradoxical?) need for an individual timekeeper[5]: everybody needed to be synchronized with the rest of the world, or at least with his professional and personal neighborhood.

Over the past few centuries, time has clearly increased its ascendancy on human activities. Financial transactions are nowadays fundamentally based on time, and the Internet and all telecommunication networks must be synchronized. Almost every action is quantified in time (and hence in money): at work, this is clear, and also for travel, either professional or personal, leisure, entertainment, etc. In the development of time measurement, one has also faced the disappearance of the mechanisms that were the visual part of the time passing. Some displays, if not all, no longer have hands but give digital values.

1.3.2 Comparison with the Possible Change in Our Perception of Space

The representation of the Earth has also changed quite a lot over the centuries. As time was being synchronized around the world, there was also a need for more accurate representation of the world in terms of maps, routes, etc. Note that although many different needs are at the origin of this requirement, time is certainly one of the most important. As the world's activity is largely based on time, it is very important to be able to evaluate the time needed for any given trip, either of people or of goods.

If we try to make a comparison between the evolution of time measurement and the evolution of positioning systems, it is certainly possible to say that positioning is today in the situation time faced more than 150 years ago with the advent of portable clocks. This was this technical feat that allowed the appropriation of time by everybody. The equivalent in positioning is now available with satellite-based positioning systems (thanks to the pioneer global positioning system [GPS]). A few features are similar between the first portable watches and basic GPS receivers of today: the similar approach of needing an identical referential worldwide, the availability of a personal local measurement, and the possibility to "synchronize"[6] with anybody else using a similar device. In addition, time and position are closely linked in GNSS (global navigation satellite systems) and this feature will help bring together the two aspects.

In conjunction, there is another technical achievement that is fundamental for the dissemination of portable positioning devices and their incorporation into everybody's life: telecommunications. When someone uses the time read

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[5] The same phenomenon is visible today with the Internet and the "permanent connectivity" feature: as globalization is not achievable for people, there is the need for individual devices allowing globalization.

[6] "Synchronize" either relates to time or to position.

on a wristwatch, it is automatically shared with others because the uniqueness of the common referential is enough. This is absolutely not the case for positioning: even considering a shared geographical referential, the position is a specificity of one person. In order to share these data with others, there is the need to communicate this information. This is why the advent of both positioning and telecommunication are bound to provide a wide development of positioning (maybe on a similar scale to what happened for time).

In the scope of this evolution, it is possible to consider that positioning could be profitable in domains such as ubiquity, or in other words, the automatic discovery of anyone's environment, or also in group management. For ubiquity, it is clear that if the positions of all people and objects were easily available, in all possible environments and at almost no expense, the environment of everybody could be discovered. The telecommunications required are available today, but not positioning (and this book deals with the most difficult aspect: indoors). An extension of this could be that people would need to define themselves with some criteria that would lead to belonging to a group of like-minded people. The above-mentioned discovery of environments could then be to find, from a geographical point of view, people or objects that belong to your group (or any other group). This is currently being implemented in the Social Networks communities with applications such as "find a friend" or "find a point of interest." The idea is to extend these applications to everything in the scope of the so-called Internet of Things (IoT). The indoor positioning of objects and people is therefore a fundamental feature.

When compared to the evolution of time and its impact on society, it is even possible to imagine that positioning could be used in many other ways (considering positioning as the combination of positioning and telecommunications). Knowing how people are moving around in the city,[7] it is possible to organize the "waves" of movement and then to define the policies to be followed by the town council in terms of roads, infrastructure, and public transport, for example. This aspect relating to flow management is also a strong concern for public buildings such as airports or museums, for example. This leads us to transportation. The health and safety authorities could also use positioning-related devices: emergency calls are already in use, but one can imagine that the above-mentioned group management approach could be part of the management of any emergency call. For example, if somebody fell ill in the street or in a building, an alert could be transmitted to people who are geographically close and who have been identified as competent in this medical field. This raises the problem of the definition and the access to the corresponding information files, and also to privacy issues, but could be one direction of future developments.

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[7] The proposed concept can easily be applied to a country or even to the world, as well as to smaller structures like a district or inside a company.

The current problem of “Data,” either geographical or not, and personal privacy is a fundamental one which must be dealt with urgently if one wants to provide valuable, but acceptable, services to users based on their location.

1.4 The Radio Age

The wish to communicate over long distances was described long before the radio conduction phenomenon was discovered. The first related facts are dated fourth and fifth century CE (by optical means) using fires on top of mountains, serving as “communication relays.” This approach was still used by the first optical telegraphs in the seventeenth century. Of course, the main disadvantage of such a system lies in the fact that transmission is limited to the optical line of sight and requires good “air conditions,” i.e. no fog. This problem led to the development of the electrical telegraph.

On the 24 November 1890, Edouard Branly discovered the phenomenon of “radio conduction”: an electrical discharge (generated by a Hertz oscillator) had the effect of decreasing the resistance of his “tube.” It appeared that electrical propagation was possible without cables. Further works showed that “adding” a metallic rod to the generator improved the range of the transmission (i.e. the detection was also possible further away from the generator): Alexander Popov was just about to invent antennas. The transmission path grew from a few tens of meters to 80 m. In 1896, Popov succeeded in transmitting a message over 250 m (the message was composed of two words: “Heinrich Hertz”).[8]

At the same time, Guglielmo Marconi, who was deeply influenced by the publications of Faraday and the life of Benjamin Franklin, felt that it should be possible to establish a transmission over a few kilometers. After a lot of works, he transmitted the letter “S” coded in Morse (“· · ·”) over 2400 m at the end of 1895. In September 1896, by using a kite as an antenna, Marconi achieved a 6 and then a 13 km radio path. In May 1897, a transmission of 15 km was demonstrated between two English islands (Steep Holm and Flat Holm), followed by similar performances in Italy in the La Spezia harbor. Marconi founded, on 20 July 1897, the Wireless Telegraph and Signal Company. In March 1899, the first trans-channel message was sent between South Fireland (Great Britain) and Wimereux (France): the addressee was Edouard Branly. With antenna heights of 54 m, this 51 km transmission was achieved with a global performance of 15 words per minute. In July, a 140 km path was achieved between a sea position and the coast. After this new success, Marconi was almost certain that trans-horizon radio paths were possible.

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[8] For more details, see the exciting “Comment BRANLY a découvert la radio,” Jean-Claude Boudenot, EDP Sciences (in French!).

In October 1900, Marconi started drawing up the plans of the Poldhu station (in Cornwall, United Kingdom), which was planned to be the transmission station for the first trans-Atlantic transmission. The chosen site in North America was Signal Hill, in Newfoundland, still a British colony at this time. This station was ready for experimentation on the ninth of December. From this date, it was decided that Poldhu would send the letter “S” (“· · ·”) each day between 11:30 and 14:30, Signal Hill time (the need for synchronization is definitely a fundamental aspect). On 12th July, the signal was received at 12:30, through a path of 1800 miles (3500 km), including the Earth’s curvature!

Coming back to navigation, it was only a few years later (1907) that radio electric signals were used, by transmitting time signals. As already described, knowing the time at a specific location is fundamental in calculating the longitude. Until then, this was achieved through the use of Harrison’s clocks. The radio transmission was a fantastic improvement, especially in terms of accuracy, as the signal is transmitted at the speed of light, thus greatly increasing the accuracy of the “time transfer.” The corresponding improvement of positioning is around 10 times better. The second application of radio electric waves was to use the signal as a new landmark that no longer needed to be in visible line of sight. The first such system was implemented on board a ship in 1908, together with a movable antenna that could give an indication of the bearing of the transmitter. This was the first dedicated radio navigation system. Note that many elements of positioning systems (angle measurements, time synchronization, need for ephemeris, etc.) were already present at this time.

In addition, the new radio beacons allowed positioning using measurements based on electrical properties such as the amplitude of currents or voltages, for instance. This was going to simplify the automation of the navigation systems as electrical engineering was rapidly progressing. Some approaches are still used today for positioning, especially indoors.

1.5 First Terrestrial Positioning Systems

Thus, the first systems were based on radio goniometry[9]: by having a rotating antenna and by carrying out the detection of the maximum power, it was possible to determine the direction of a landmark. The radio compass was one of the most advanced forms of radio goniometrical systems. Another approach was that used for radio lighthouses. As determining both the identification and the orientation of the transmitters had to be easy to obtain, the technique consisted of having a couple of antennas radiating complementary signals (for instance, the equivalent of A “·—” and N “—·” in Morse). When a receiver is in both main

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[9] Goniometry is the way of measuring the angle of rotation of the aerial of a wireless system in order to obtain the direction of arrival of the radio wave.

radiating lobes, the signal received is continuous. In 1994, more than 2000 radio lighthouses were available all around the world.

As local time generators (oscillators or atomic clocks) were developing rapidly, new uses of radio signals were imagined. This was the case of so-called hyperbolic systems. The basic principle states that all locations having the same difference of signal travel time to two fixed points, for instance, two radio transmitters, lie on a geometrical figure, which is a hyperbola when dealing in two dimensions (more generally, the mathematical locations are defined by a quadric). The focal points of this hyperbola are the transmitters. As signal processing capabilities increased, such time difference estimations and measurements became possible. Note that the synchronization at the mobile receiver's end is thus avoided as long as time differences are carried out. The basic idea was then to obtain two such differences in order to allow the calculation of the intersection point of the resulting two hyperbolae (see Figure 1.2): this approach leads to a theoretical single point in a two-dimensional space.

The first system that used this technique was the Decca,[10] which came into operation at the end of the Second World War. It worked within the frequency band of 70–128 kHz, allowing approximately 450 km of operational range. The resulting accuracy was in the range of a few hundred meters, depending on the

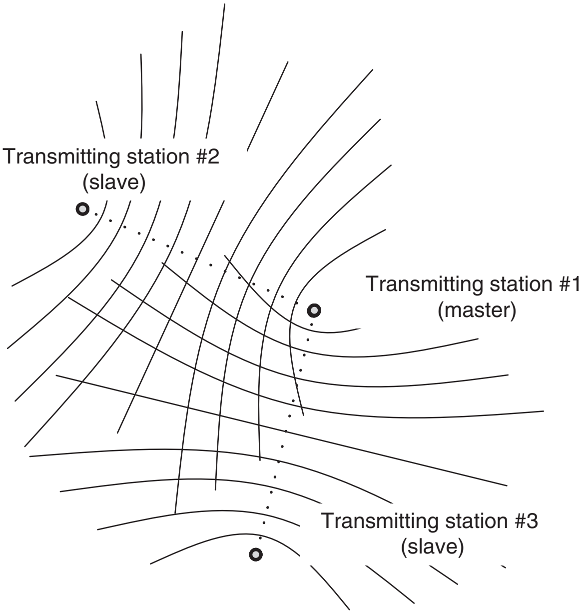

Figure 1.2 Representation of the hyperbolic approach.

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[10] Proposed by the Decca Navigator Company.

propagation conditions. The new era of radio electric signals allowed a rigorous evaluation of accuracy, a very important parameter.

The enhanced-LOng RAnge Navigation system (e-Loran) is also a hyperbolic system that added new features concerning the modulation scheme, based on pulse trains forwarded by each master and slave station.[11] These first terrestrial systems provided "local" area coverage, even though this coverage can be quite large (this is the case for LORAN). However, some people imagined an even more ambitious project that would be the ultimate version of a terrestrial system with a global coverage: the Omega system. It was made up of eight stations using very low frequency (VLF) band in order to have a complete coverage of the Earth. It was still a hyperbolic approach: each station transmitted sequentially, always in the same order for about one second (the duration of emission is specific to each station). The emission consisted of pure continuous waves (no modulation scheme) at 10.2, 11.33, and 13.6 kHz, respectively. The global accuracy was generally better than 8 km.

The major reason for the poor accuracy of the above-mentioned systems is included in the propagation modeling (this point has constantly driven the evolution of modern systems). The reader should notice that this aspect is also the main source of difficulties for indoor positioning when dealing with radio systems, but not only. Indeed, a large majority of approaches are limited by propagation aspects.

1.6 The Era of Artificial Satellites

In the late 1920s, physicians and mathematicians showed that it was theoretically feasible to imagine artificial satellites launched from the Earth's surface and orbiting the Earth. Of course, a lot of research was still required, but it was thought possible. On 4 October 1957, the Soviet Union launched Sputnik-1 (see Figure 1.3), called the "basketball," weighing 183 pounds, on an elliptic orbit with a 98 minute revolution period.

To prove that a satellite was actually orbiting the Earth, it was planned that it should transmit a signal. Sputnik used a 400 MHz carrier frequency with sound modulation data. In such a way, once demodulated, it was possible to "hear" Sputnik.[12] Nothing was really known about this flight: the orbit, the speed of the satellite, the duration of the transmission, etc. Therefore, it was a fantastic opportunity to carry out some tests. Among others, George C. Weiffenbach and William H. Guier, members of the Applied Physics Laboratory of

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[11] The master station is the one that masters the time. The slave stations have to be synchronized with the master station.

[12] What was then "hearable" can be listened to at: https://www.youtube.com/watch?v=r-bQEiklsK8.

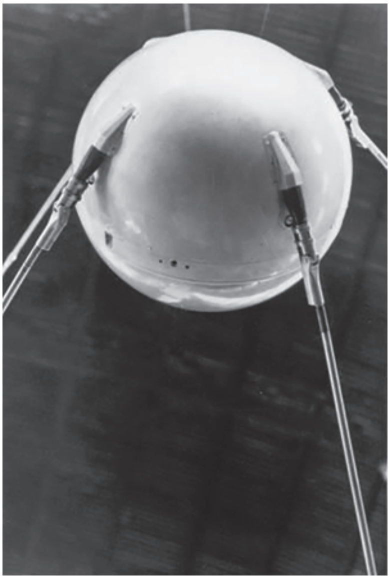

Figure 1.3 Sputnik, called the "basketball."
Source: Courtesy of NASA.

the Johns Hopkins University, carried out such investigations. They succeeded in determining the Sputnik's orbit by analyzing the Doppler shift[13] of the signal while the satellite was in radio visibility, i.e. for about 40 minutes of the 108 minutes of a complete revolution of Sputnik.

The method they used to achieve such a goal was of fundamental importance as it is the starting point of all modern satellite navigation systems. The measurement was the Doppler shift, the unknown variable was the orbit of the satellite, and another piece of data was the actual location of the place of observation (i.e. the laboratory). After about three weeks of observation and a few calculations, they finally showed that it was possible to calculate the orbit, knowing both the Doppler shift and the exact location where the measurements were carried out. It has to be remembered that, in 1957, this was at the height of the Cold War between the Soviet Union and the United States. The US Army, and more specifically, the US Navy, had a difficulty concerning the positioning of its fleets cruising in northern oceans. These ships were equipped with missiles to which precise missions could be allocated. The problem was that, although the guidance of such a missile was controlled by an inertial system of high quality, the starting location of the flight was still obtained through the use

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[13] The Doppler shift is the physical phenomenon that shifts the frequency of any wave transmitted, depending on the relative speed between the transmitter and the receiver. Let us define D as the distance between the transmitter and the receiver: the frequency received is increased when D decreases and decreased when D increases. Note that this phenomenon is a physical time compression of the signal and applies to all waves (sound, radio, light, etc.).

of terrestrial systems, i.e. not very accurate. A more accurate system would be of great help for this specific purpose.

Frank McClure, head of the department, made a suggestion: would it be possible to invert this problem? That is, would it be possible to be able to calculate the location of the observation point, knowing the orbit of the satellite, by carrying out the same measurements as those achieved to define the Sputnik orbit, i.e. the Doppler shift of the received signal. Thus, the problem of satellite positioning was solved, thanks to Sputnik and led to the Navy Navigation Satellite System (NNSS), or "TRANSIT" program, which was launched in 1958, directed by Richard Kershner.

The first satellite was launched in September 1959, and before the end of 1964 (an amazingly short time for anyone working on modern projects), 15 launches had been carried out with 8 more for research purposes. These eight were related to the program and concerned the following:

- the establishment of a network of terrestrial surveillance stations,
- the determination of the terrestrial gravity, which is of primary importance in order to predict the orbits of a satellite over a long period (12 hours in the case of TRANSIT),
- the definition of terrestrial and maritime receivers.

The TRANSIT system became operational for the Navy in 1964. The mean accuracy obtained was typically in the range of 200–500 m.

The limitations of TRANSIT were the starting point for the specifications for the second generation of US satellite-based positioning system, which were as follows:

- *Availability*: 24 hours a day, 365 days a year, for all the covered locations and whatever the meteorological conditions (we mentioned this point concerning the terrestrial systems, for which the propagation conditions are of great concern). This last point has fundamental implications and modern systems are still spending a great deal of effort on improvements to propagation-related matters.
- *Accuracy*: three-dimensional positioning with delivery of speed (real speed vector in three dimensions too) and precise time (one has to remember that time delivery was the first application of radio signals to maritime and navigation domains in the early years of the twentieth century).
- *Coverage*: the whole planet should be covered with an extension to space (low and medium Earth orbit satellites usually position themselves by using GPS signals).

1.6.1 GPS System

As the TRANSIT system was made operational in 1964 for the US Navy, the early works on what would become, in 1973, the GPS program started with tests on both the CDMA scheme (code-division multiple access) and the PRN code approach (pseudorandom noise). These two techniques, widespread nowadays in radio systems, and more specifically in wireless telecommunications, were quite innovative concepts. In 1967, the US Navy started the TIMATION program to assess the effect of relativity, both special and generalized, on a satellite-based atomic clock.[14] In 1973, the programs related to satellite navigation from both the US Navy and the US Air Force merged into an official "Navigation Technology Program" called "NAVSTAR GPS," sometimes referred to as "Navigation Satellite with Time and Ranging Global Positioning System."

After the first stage of research programs, phase II started, in 1978, with the launching of the first four NAVSTAR satellites. From 1978 to 1985, 11 satellites were launched (called block I), and from 1989 to 1997, the 28 block II/IIR operational satellites followed. In 1985, seven satellites were available allowing about five hours a day of positioning. The 24 nominal satellites were in orbit in 1994 and the GPS system was declared operational in 1995.

The major difference with the TRANSIT system is that it is now based on a trilateration technique,[15] i.e. multiple distance measurements are carried out in order to allow the receiver to calculate a fix (TRANSIT was based on Doppler shift measurements).

1.7 New Problem: Availability and Accuracy of Positioning Systems

Our current topic, indoor positioning, has not been solved with GNSS. Moreover, the availability of these systems on a large scale led to questions concerning the continuity of the positioning service in all kinds of environments. In addition, the advent of high-performance portable telecommunication terminals has brought about the need for very versatile positioning systems. The very low cost, the ease of integration, and the lack of alternative systems have also led to a large dissemination of GNSS chipsets, leading in turn to a more and more frequent use of them. Thus, the way positioning is achieved with GNSS has indeed become a standard and it is quite difficult to suggest other visions (for example, a positioning that would not be continuous in time and space).

For about 20 years, various techniques and technologies have been developed, evaluated, and sometimes implemented in order to cope with this continuity. It does not seem to be the end of the story as no approaches have demonstrated that they answer the question adequately. The problem

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[14] GPS is the first widespread system that must implement both theories of relativity, in order to obtain accurate positioning. Neglecting these effects would lead to a 10 km error per day!

[15] This technique is described in Chapter 3.

indeed seems linked with the expectations of the users, building managers, or ordinary citizens, who seek accurate technological solution at no cost. This is the starting point of a more complete discussion concerning the real problems of indoor positioning, dealt with in the next chapter.

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