Localization

Elaborated by Pietro Valente, 12 February 2021.

Outdoor localization

"Where am I? The question seems simple; the answer, historically has proved not to be"[1] with these words the American magazine "Beyond Discovery" in 1997 introduced a technology born just 4 years ago, whose potential was already beginning to be understood: the Global Positioning System.

It all began in 1957 when the Soviet Union sent *Sputnik 1* into space, the first satellite in history, and research conducted by the Massachusetts Institute of Technology (MIT) was able to accurately establish the orbit of the satellite, based only on the frequency of the radio waves emitted[2]. This discovery was perfected over the next few years and proved to be very useful when, in 1973, the US Department of Defense decided to look for a technology for global localization, to be used for military purposes. It was after a brainstorming session at the Pentagon that the concept of GPS was born.

The idea was to create a network of 24 satellites that would allow at least 4 to be detected at any point on earth. In this way, by exploiting the triangulation of the received signals, it was possible to obtain a position with acceptable precision. Since its inception in 1978 the expedition of satellites has taken several years and ended in 1994; The system was declared operational the following year.

Meanwhile, in 1983, when the *Korean Air Lines Flight 007* airliner was shot down by the Soviets for mistakenly invading a forbidden area of the sky, the then President of the United States, Ronald Reagan, decided that upon completion of the technology, it would also be made available for civilian use[3]. [Initially, however, a distinction was established between use for civilian users (SPS service, *Standard Positioning Service*); and military use (PPS service, *Precision Positioning Service*). The difference was given by the accuracy of the signal: SPS users could count on 100m horizontally, 300m vertically and no more than 2m/s in speed, against their respective 22m, 27m, 0.2m/s for PPS users[4]. The degradation of performance for the SPS service was voluntary (*Selective Availability*) and was carried out for reasons of national security.

In May 2000, under the direction of President Bill Clinton, the U.S. government decided to stop modifying the signal to make GPS more responsive to civilian and commercial users around the world.

It should be emphasized that the operation of this technology was possible thanks to some scientific and engineering advances that took place in the '900: in particular the theories of relativity of Einstein and the invention of atomic clocks. If time dilation (special relativity) and gravitational redshift (general relativity) were not considered, there would be an error in the position in the order of 12km[3] per day. Moreover, since to calculate the distance between the transmitter and a satellite a signal is sent to them and the travel time is measured, the invention of atomic clocks in 1949 was crucial. In their operation the basis of time is determined by the resonance frequency of an atom, this allows to have an extreme precision (already a billionth of a second to the creation of the GPS)[5].

Over the years the accuracy of the signal has been growing thanks to more accurate atomic clocks, more efficient receivers, enclosed in smaller and smaller chips, but above all thanks to the growing number of satellites, which to date has reached 34 and allows you to cross the data of up to 12 satellites at the same time.

In addition to GPS, other satellite networks have been built over time such as the *Global Navigation Satellite System* (GLONASS). This Russian technology, born in parallel with the American one, at the end of the 90s had experienced a decline in performance, but was then restored in the 2000s with large investments and can now boast of being the second navigation system in operation with global coverage and precision comparable to GPS[6].

Another interesting satellite navigation system, created by the European Union, is Galileo which came into operation in 2016 with 18 satellites. The final project will involve the use of 30 satellites (24 operational and 6 spare parts), available by the end of 2021[7][8]. This technology will improve the scenario offered by GNSS by acting on three characteristics: accuracy, availability and coverage.

Initially Galileo was seen by the United States as an attack on its communication system and therefore strongly hindered, delaying its creation, until it was understood that the project was not designed to replace or hinder the American one, but as a useful tool to support in civil uses, applications for which GPS was not initially designed and therefore has many shortcomings[9]. Thus was born the first collaboration between two global localization systems.

Indoor localization

As we have seen*, outdoor* geolocation has reached high and satisfactory standards. However, the signals emitted by satellites generally fail to be intercepted indoors, or otherwise with a much lower accuracy (50m). This has led to the development of alternative technologies to solve this problem.

In 1998 and 1999, Bluetooth and Wi-Fi (or WLAN) were invented respectively[10][11]. These technologies were actually preceded by the studies of Hedy Lamarr[12], who in 1940 had deepened the technique of frequency switching. Bluetooth and Wi-Fi are very similar because they are both wireless communications that take advantage of digitally embedded information about radio frequency signals to exchange data. The main difference between the two lies in the range of action: while Bluetooth covers an area of about ten meters, WLAN networks can reach up to several kilometers.

At the beginning of the 2000s these systems began to be incorporated into mobile phones and their diffusion, combined with the economic cost, stimulated several studies to look for an indoor localization technique that would use them. Much of this research has focused on power measurement (RSSI) with data intersection using a method of multilateration and fingerprinting. The latter approach is to map the area of interest by creating a database of known patterns associated with locations, so that at the time of measurement you only have to compare the data received with those in the database.

One of the first systems that used these two techniques with WLAN technology was RADAR in 2001[13], developed by Microsoft Research, which managed to obtain an accuracy of 2/3 metri thanks to the use of a radio map, which is a search table that contains a set of data on the signal strength and the locations of the buildings where the signals were measured. To improve its estimation, RADAR takes into account the recent history of transmitter movements and dynamic changes such as temperature, the number of people present and any other environmental factors that influence the radio map.

In 2003, Feldmann and other colleagues studied a localization technique that used Bluetooth power triangulation with least squares estimation. The authors stated that they achieved an accuracy of 2.08m over a maximum distance of 8m[14]. In addition, the system is sensitive to signal attenuation and reflection due to obstacles between the person carrying the Bluetooth device and the access points.

Another interesting solution, which was found in 2003, is the *Cricket Indoor Location System*: a hybrid system that combines ultrasonic waves and radio frequency signals. A technology that has the advantage of obtaining an accuracy of only 10cm, but at the same time requires the creation of a network with special sensors, a solution that overall is quite costly (for example $ 150 for a 10m x 10m room)[1 5][16]. If the main purpose is only the localization of a restricted area, this solution may still be acceptable, in larger spaces the cost begins to be excessive and it becomes preferable to use other technologies such as Bluetooth and WLAN , which also have the advantage of having additional features such as data transfer.

In 2006, the cheapest *Bluetooth Low Energy* (BLE) was invented and also has a very low power consumption, which allows fixed emitters to run on batteries for several months or even years.

Given the parallel development of both Bluetooth and Wi-Fi for location solutions, in 2015 Faragher and Harle made a quantitative comparison through fingerprinting showing how Bluetooth receivers are more effective[17]. Some systems that combine the two technologies have also been studied, showing how the accuracy of their joint use is better than normal multilateration, resulting more stable even when there is an attenuation parameter of 45%.

Other interesting apps for localization, developed in 2013, were *iBeacons* and *Freeloc.*

Apple's iBeacons is a *Bluetooth Low Energy* (BLE) application designed for tracking purposes, which takes advantage of BLE's short range to determine when the user is near a transmitter. From a software point of view, *iBeacons* has been incorporated into the operating system of Apple devices (from iOS7), so that it can be launched even without user intervention[18]. Since then *iBeacons* has been installed in hundreds of Apple Stores and numerous other stores, raising privacy concerns, because at all times the user's location is known to the *iBeacons* system, which may not be to the user's liking. An additional problem lies in the inability to remove the application, since it is part of the operating system.

The *Freeloc* app uses Wi-Fi technology instead and, unlike other systems described above, in this case it is each user's app that automatically collects Wi-Fi location information, performing a process that contributes to the the construction of the database. Of course, since users who carry a smartphone with the application continue to carry out their normal activities even while moving, the measurements are not very accurate[19]. Another problem concerns the possibility for each user to have a different mobile device, so the signal strengths are not measured in the same way. Although more optimized and practical than the RADAR system, *Freeloc*, due to the problems presented, still has a similar signal accuracy.

In the last decade we have tried to improve the accuracy of systems by integrating sensors, increasingly advanced, in mobile phones. In particular, thanks to the internal three-axis accelerometer, the three-axis magnetometer and the orientation sensor, it is possible to understand, with an acceptable margin of error, when a step is made and in which direction. To predict the next location, you need to know the length of the step. This measure depends on many factors such as speed, walking style and height of the person. There are two main methods of measurement: either the average length of the human step is used, which is around 0.74m[20]; or the length of the step is estimated starting from the height. With this information, knowing the starting point, it is possible to trace the movement of a person even if, using only the sensors, a rather inaccurate estimate is still obtained. While as we will see if the sensors are integrated with other systems you can get much better results.

Many studies have therefore gone in the direction of deepening the potential of the integration of sensors with Bluetooth and Wi-Fi. For example, the one carried out in Olderburg, Germany in 2017[20]: a Kalman filter was chosen to integrate trilateration and dead reckoning (which is the process of calculating the current position of a moving object using a previously determined position). In this research the goal was to have the most faithful representation possible of the path of a person with a phone in a room. The solution adopted was to calculate the estimate of the position through dead reckoning, that is, the previous position added to the estimate of the step also taking into account the relative direction. This process is repeated for all Bluetooth sources (which being a trilateration are at least three) and their data is then intersected. The results obtained from the experiment were very good, with a very stable system that can boast the accuracy of 1m.

A further technique for IPS (*Indoor Positioning System*) is given by Computer Vision, which uses the information collected by the cameras and image processing techniques to identify and track objects. We identify two configurations: in the passive approach, the camera is worn by the user or object to be monitored and captures images from the perspective of the subject. Scanned images can be compared to location-related files that were previously stored in a database. In the active approach one or more cameras are fixed in the environment in which the subjects will be monitored[21].

Some projects belonging to the passive approach of the mobile camera use *visual odometry* (VO) to update the user's position. VO is not a recent approach, it has existed for about 30 years, but it has been gradually improved both in terms of efficiency and accuracy, as demonstrated in the *Intel® RealSense™ Tracking Camera T265* (2019). This product manages to obtain excellent performance despite being very light and low power; it is no coincidence that it is aimed at developers in the field of robotics. To work, this camera uses a V-SLAM (*Simultaneous Localization And Mapping*) that allows you to store the surrounding space instantly thanks to the comparison between the two fisheye lenses and the infrared sensor, and at the same time to memorize the path that the object is traveling[22].

In conclusion, the analysis presented in this paper shows that today the accuracy of global satellite tracking systems are within everyone's reach, with devices that cost less than 100 euros, which are already integrated into all mobile phones. As far as indoor tracking systems are concerned, a lot of progress has been made, although we have not yet arrived at an adequate solution in the relationship between the level of precision and the cost of technologies.

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Sources

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