Small Publications in Historical Geophysics

No. 17

CPS – A Forerunner to GPS Invented by an Åland Traveller in the 1700s

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Summer Institute for Historical Geophysics
Åland Islands

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1. Basic principles of GPS

Around 1989 there was a break-through for a completely new method for determining coordinates of geodetic stations: the use of satellites through the Global Positioning System, GPS. This has now become a standard tool for positioning on the Earth's surface. Its basic principles are well known and could be listed, in simplified form, as follows (see e.g. Seeber, 2003):

1. No sight between geodetic stations is needed.
2. From each station a number of distant moving objects - satellites - are observed.
3. For each moving object the distance between the object and the station is determined.
4. The distance is found by measuring the travelling time of a wave with a known speed - a radio wave - transmitted from the moving object.

This modern positioning method has completely replaced triangulation, in which sights between the stations were necessary.

2. Basic principles of CPS

Although the above method for positioning may seem modern, its basic principles can, in fact, be said to have been proposed already 250 years earlier, in 1741. That time was actually close to the break-through for triangulation, but already from the beginning there were problems fulfilling the requirement of having sights between the stations. In a short paper in the Transactions of the Royal Swedish Academy of Sciences, Meldercreutz (1741) proposed a positioning method based on principles that may be formulated in the following way:

1. No sight between geodetic stations is needed.
2. From each station a number of distant moving objects - war ships - are observed.
3. For each moving object the distance between the object and the station is determined.
4. The distance is found by measuring the travelling time of a wave with a known speed - a sound wave - transmitted from the moving object.

As can be seen, these principles can be said to be the same as for GPS. Only the technology is somewhat older: Sailing war ships instead of satellites are suggested, and sound waves instead of radio waves; see Figures 1 and 2. Let us call this method CPS - Coastal Positioning System.

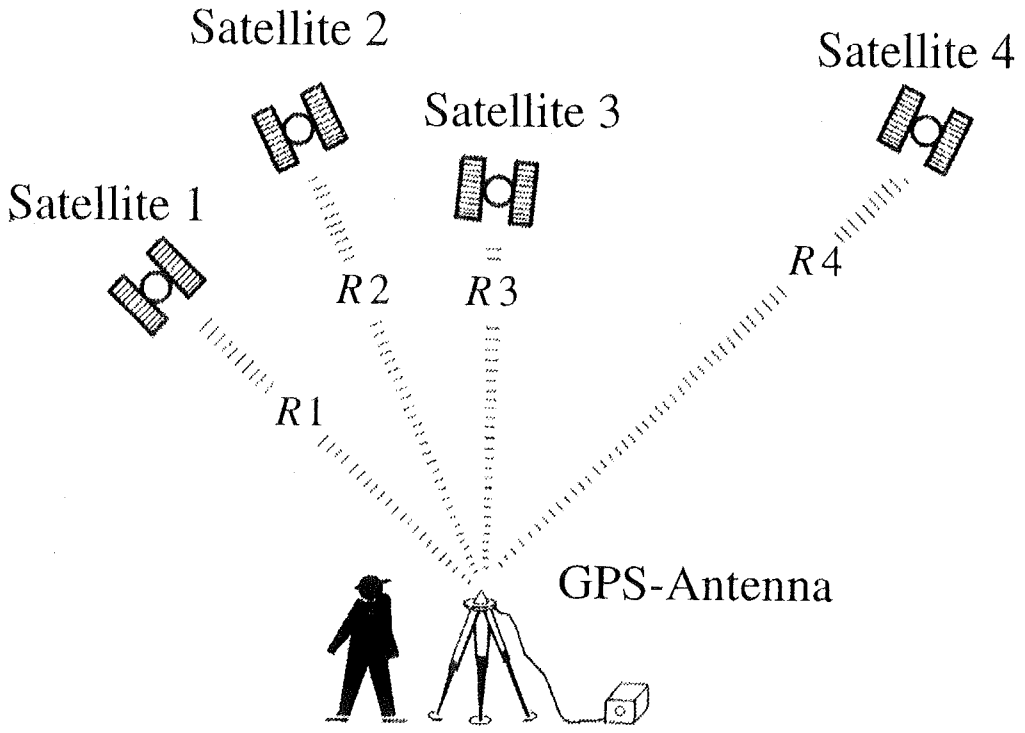

Figure 1. The basic idea of the Global Positioning System, GPS (from Seeber, 2003).

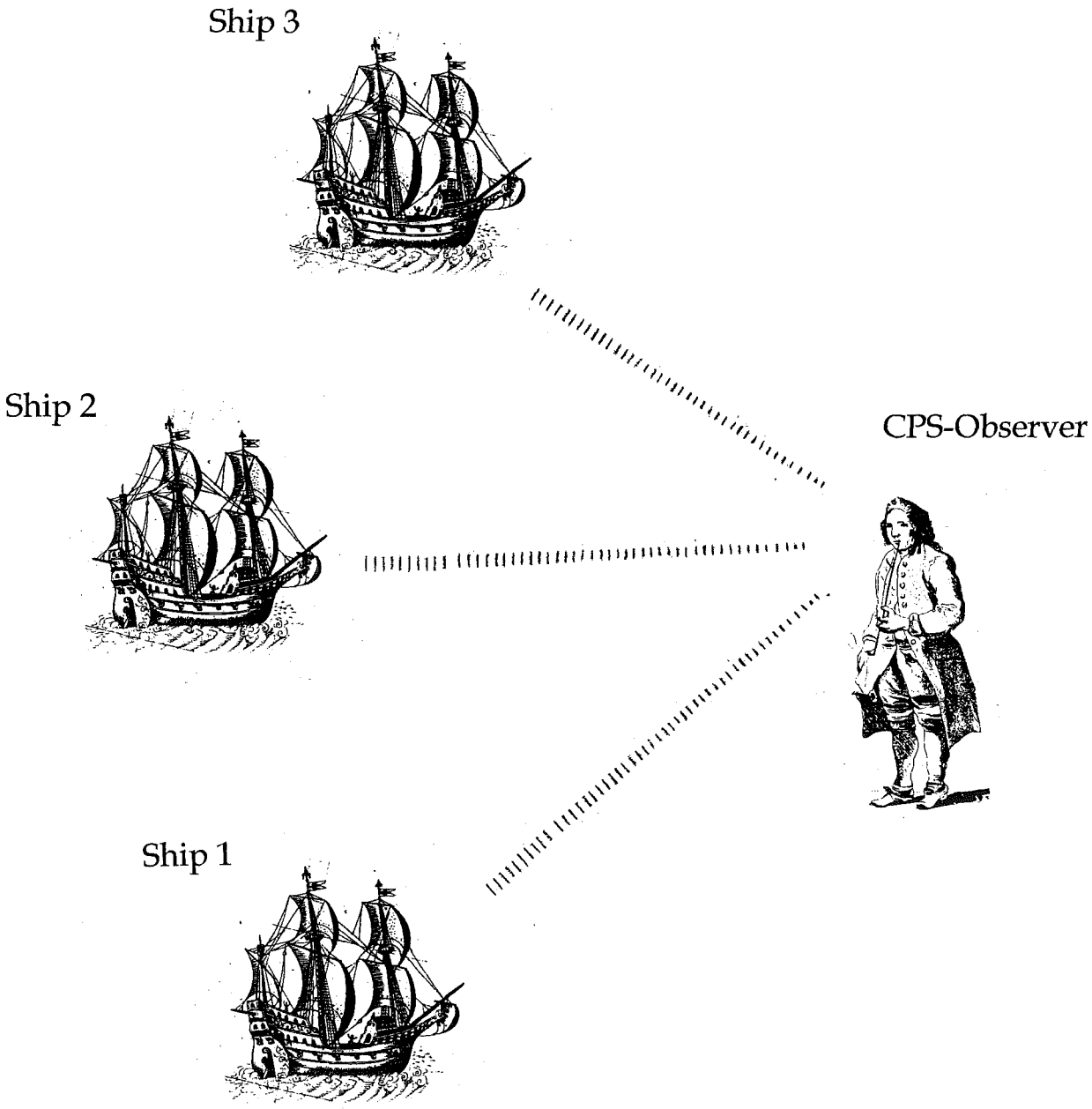

Figure 2. The basic idea of the Coastal Positioning System, CPS.

3. The scientific and practical background

Meldercreutz may be described as a mathematician with a special interest in practical applications of mathematics. He had started as a pupil of Celsius, and had then accompanied Celsius on his long study tour through Europe, visiting astronomical observatories and scientists. After that Meldercreutz also had briefly visited the triangulation performed by the French arc measurement expedition in northernmost Scandinavia, headed by Maupertuis and with Celsius as one of the participants. When coming up with his idea of CPS in 1741, Meldercreutz was a teacher of military mathematics at the Fortifications Corps in Stockholm; he later became professor of mathematics at the University of Uppsala.

Around the Baltic Sea there was at that time a great need for better coastal maps and nautical charts. The existing maps and charts were based on old astronomical latitude determinations and only few and very uncertain astronomical longitude determinations. Triangulation, used for the French arc measurement in the north, had not yet been applied for making charts. Especially the important travelling and postal route between Sweden and Finland through the Åland Islands with its extensive archipelago was in need of a more reliable mapping. Meldercreutz had married a girl from the Finnish side of the Baltic, which made him travel several times between Sweden and Finland across the Åland Islands, probably along the mentioned route (it is known that he died on Åland along this route). Here he must have had unlimited possibilities to experience the lack of knowledge of the positions of islands and coasts; there was no reasonably accurate map or chart available. When, later on, triangulation was introduced for mapping the Baltic Sea, the Åland Islands was the first area to be measured.

4. How CPS was intended to work

According to Meldercreutz (1741), there could be different ways to apply CPS. One way would be to determine the position of a coastal station through the observations of at least two war ships (and also the position of a ship through corresponding observations of at least two coastal stations). Another way would be to determine the relative positions of two coastal stations through simultaneous observations of the war ships from both stations. Again we recognize similarities with GPS, now in the form of absolute and relative GPS. Meldercreutz suggested the possibility of using a whole fleet of sailing war ships for determining the (relative) positions of a whole set of stations along the coast.

In order to determine the distances from the war ships to a station one was supposed to use a sound wave travelling through the air. The sound would be produced by firing a canon on board the ship (see Figure 3). This facilitates time-keeping: When you fire the canon, the observer at the station on the coast will immediately see the light of the flame and start recording the time. A number of seconds later the thunder from the canon will be heard by the observer, who will then measure the time elapsed, i.e. the travelling time of the sound wave. Thus, time-keeping in CPS is sufficient to do at the station, while in GPS time-keeping is needed both at the station and in the satellites (requiring an extra satellite for calibration of clocks).

To calculate the distance from the measured travelling time one would then need to know the speed of the sound wave, c, through the air. Meldercreutz recommended for the speed of sound a value based on British, French and Italian determinations as compiled by Triewald (1735), c = 586.4 Swedish ells per second = 1172.8 Swedish feet per second. With 1 Swedish foot = 0.2969 m we obtain c = 348 m/s. This value is only 1 % larger than the correct value for air of a temperature around 22°C, and 2 % larger for air of a temperature around 16°C.

5. Why did not CPS work as intended?

There is no sign of CPS ever having been applied in real field work. Why? One can assume that there must have been two problems.

The first problem would be to determine the positions of the war ships. This is a problem also with the satellites in GPS. In contrast to a satellite, however, it is hardly possible to compute the motion of a sailing war ship in advance with sufficient accuracy, i.e. there is no reliable "broadcast ephemeris". On the other hand, there could be a kind of "precise ephemeris", where you afterwards calculate the ship's position from actual measurements on board the ship. If the depth of the water is not too large, this could be made easier by casting anchor while the measurements are going on, a possibility not available for satellites. Still, great efforts would be needed to obtain sufficiently accurate ship positions.

The second problem would be to measure the time with sufficient accuracy. This was no doubt the main problem. Supposing a ship to be located, say, 5 nautical miles (nearly 10 km) off the coast, the sound of a fired canon would take some 30 seconds to reach the coast. To be useful this would require the time to be measured with an accuracy of fractions of seconds. This was not possible in the field with the clocks available then.

In summary, the idea presented at this early stage in the development of positioning is quite modern, although it could not be realized with sailing-ships and fired canons, but had to await satellites and radio signals!

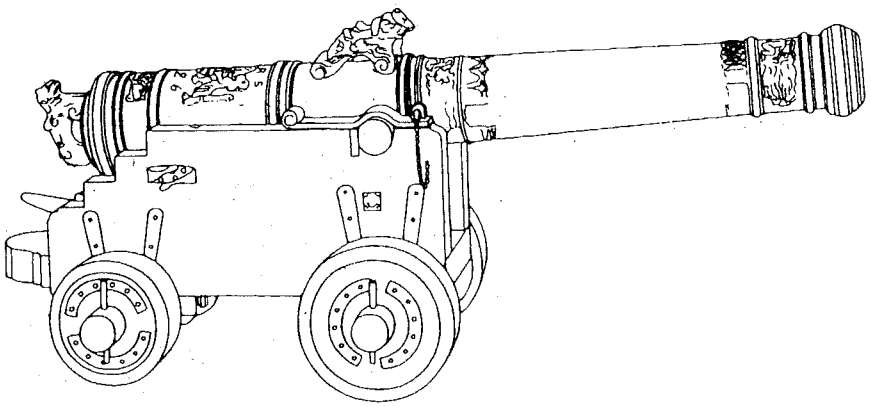

Figure 3. The transmitter of the travelling wave in CPS.

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