PLANET CHANGE

GNSS:

Logistics from space

Teachers manual

Co-funded by the Erasmus+ Programme of the European Union

Planet change is the short name of an EU Erasmus+ project aimed at VET teachers and their students. With small activities, the idea is to create awareness about sustainability and acquire 21st century skills. All this is done in a technical context, mostly from space technology.

www.planetchange.eu

Contents:

1. General information

Purpose: The objective of the task is to understand the working of GNSS (Global Navigation Satellite System) and the importance of GNSS in daily life.

Target group: (Technical) VET schools

Target group, age: 12-20Y

European Qualifications Framework level: 2?/3/4

Duration: 1x45min

Location: Classroom

Materials: Computer with internet connection

Software: Any normal browser, no special requirements.

Background: No need for previous background on the topic (just knowing how to use an internet browser).

Topic

Theme

Logistics: GNSS

Keywords

Logistics, GPS, Galileo, GNSS, accurate timing

Activity

Learning Objectives

The student will get better knowledge and training about:

1) What is GNSS
2) How GNSS and trilateration works
3) The uses of GNSS outside of navigation
4) Implications of errors in the timing signal

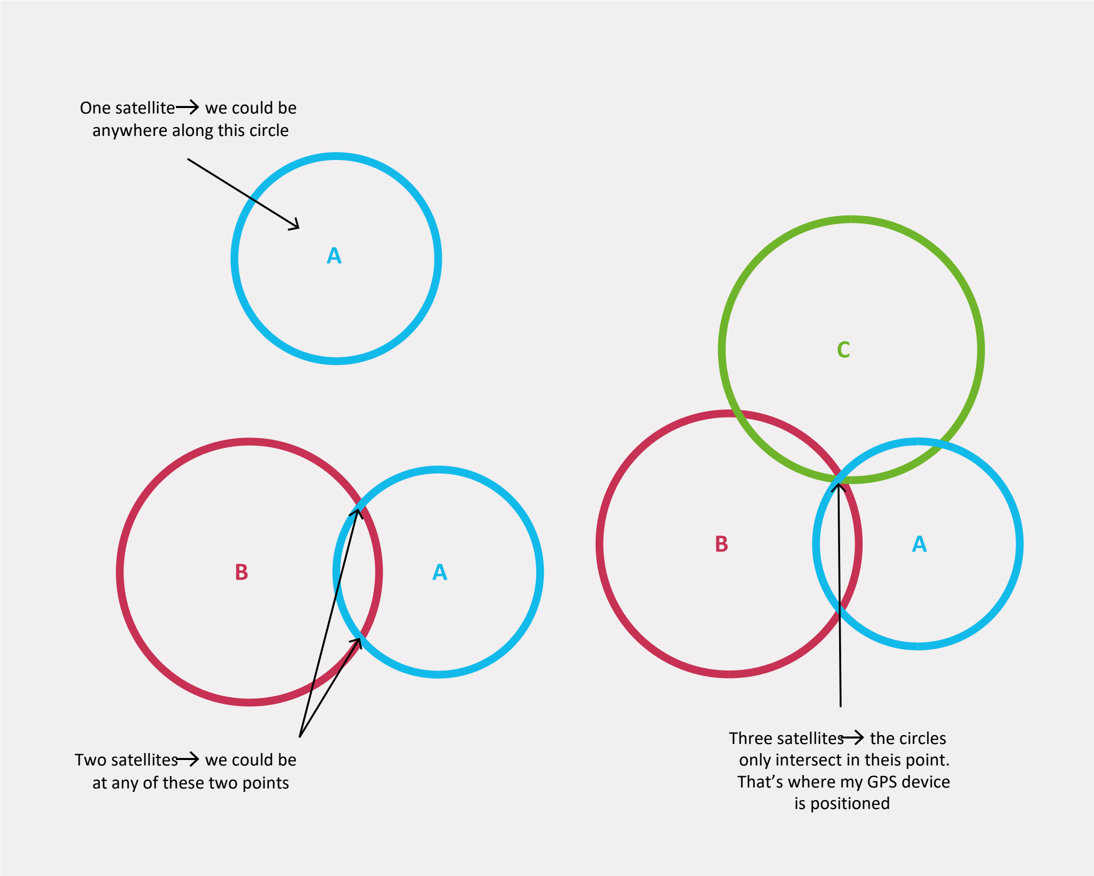
BACKGROUND

There are several Global Navigation Satellite System(s) (GNSS) orbiting the Earth. The most well-known are GPS (operated by the US), and Galileo (operated by the EU). The best known use is to locate your position on the planet. GNSS positioning works on fairly simple principles, but the installation and application of such a system requires incredible precision.

Two main mathematical ideas underpin the GNSS positioning network. Trilateration is the first concept and it is based on finding the position of a GNSS device from three distances. The second idea is the relationship between the speed of the signal (speed of light, c = 299 792 458 m/s), the time taken for the signal to travel and the distance travelled. All that is needed for this second concept is the equation:

Distance travelled (m) = Speed (m/s) x Time (s)

Trilateration works by finding your position on Earth once the location of GNSS satellites orbiting the Earth and their distance from your location are known. Since we cannot physically measure the distance of these satellites directly, we need to use the known speed of the signal sent by the GNSS satellites and the time the signals were sent. This is quite easy, because satellites send out signals constantly. Since these are electromagnetic signals, they will always travel with the speed of light (299 792 458 m/s in vacuum). So if we know the time that the signal took to reach us, we will know the distance to the satellite. Assume that your GNSS receiver detects the signal from only one satellite. All we could tell then, is that we could be anywhere on the surface of a sphere. The radius of that sphere is equal to the calculated distance (time difference times the speed of light) from the satellite. If we only received signals from two satellites (satellite A and B, for example), we could tell that we are somewhere along the circle drawn by the intersections of the spheres described by the two signals. [see the Planet Change app for visualisation] With a third satellite signal it will give two points where you could be, but since one of them will be on the Earth, this is where you are located (the Earth is in fact a fourth sphere to distinguish between the 2 points). We can simplify this concept in 2D, using circles rather than spheres (this is also what the activity will model).



In 3-D it will give 2 points where you could be, but since one of them will be on the Earth, this is where you are located (the Earth is in fact a fourth sphere to distinguish between the 2 points).

For more information about this concept you can look at one of the following videos:

Everyday Einstein: Demonstrating GPS Trilateration - YouTube

How GPS works? Trilateration explained - YouTube

The need for accurate measurements of time

Because of the speed of light (299 792 458 m/s) is so high, it means that a mistake of 1 µs (a millionth of a second) in the satellite signal or the clock of your receiver already gives an inaccuracy of about 300 meter. The timing of GNSS satellites therefore need to be very precise and accurate. This amazingly accurate timekeeping is achieved by the atomic clocks carried by the GNSS satellites.

If we used ordinary clocks, our positioning calculations would be way off target. Of course, the clocks inside our mobile devices are not atomic clocks, but they need to know the time accurately. This is why a fourth satellite is necessary for accurate location information. By using this fourth satellite you can take out the error by the timing inaccuracy of your mobile device.

PREPARATION IN ADVANCE

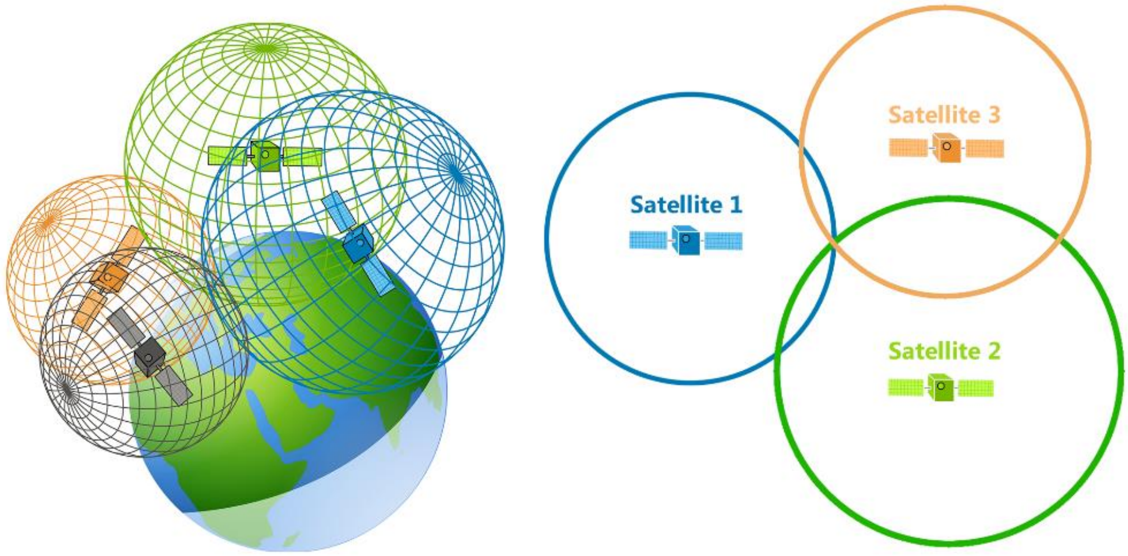
For the trilateration class demonstration:

1) 3 x mm-accurate tape measures, at least 3m but preferably 5m in length
2) Have a way to register results from students (whiteboard, paper, ….)
3) Place 3 dots on the floor, in such a way that they do not easily move. This can be small coloured markers like sticky dots, or a paper taped to the floor (it should not move) with a dot on it. Label these dots A, B and C. NB if you want you can skip this part and let the students choose the locations at the beginning of the activity.
4) Place the paper with the many dots to the floor, preferably a significant way out of the middle of the three dots A, B & C and fix it there, e.g. by tape. Make sure that it will not move.
5) If you have decided the choose a dot on the paper (let's call it point P), then measure the distances from this point P to the dot A, B and C. So you will have a distance A-P, B-P and C-P. Write these numbers down and to which distance they apply (A-P, B-P and C-P). If the students are to choose the dot you can skip this step.

It might also help if you have watched one or both video's on how GPS works (see background information) before the lesson and ensure you have access to YouTube.

2. Introduction

GNSS (Global Navigation Satellite System(s)) is a collective name for all systems that allow you to determine your position on earth using satellites. The best-known examples are GPS from the Americans and Galileo from Europe. In this activity you will watch a video that explains how this works. Then, you will simulate how a GNSS device finds its position on Earth using the signals from GNSS satellites.



You will be able to answer questions about how GNSS works and why the precision of atomic clocks is important in this process.

Finally you will discuss the other functions of GNSS outside navigation.

Description of the activity

The students will simulate how GNSS works through trilateration.

3. Lesson

Part 1: Explanation of GNSS and its uses (5 min)

Ask the students if they know what GNSS is.

Explain the acronym (GNSS - Global Navigation Satellite System) and tell that GPS is part of it, but also other systems like the European Galileo system. Show the video What is Galileo? - YouTube

Part 2: Explanation by practical experiment of trilateration (20 min)

You can start with the following video:

Everyday Einstein: Demonstrating GPS Trilateration - YouTube

Class demonstration of trilateration:

► 3 x mm-accurate tape measures, at least 3m but preferably 5m in length

► Small coloured markers (sticky dots)

► Whiteboard and markers (for recording results where students can see them)

1. If the dots A, B and C are already placed you can continue with step 2. If no positions for the "satellites" are yet indicated (step 3 of the preparation has been skipped), ask three students to stand up to five metres apart (preferably as far as possible) from each other in a triangle. Each places a marker (such as a small sticky 'dot' on the floor) where they stand. If possible mark them A, B and C.
2. If the paper with the dots is already placed go to step 3. If not let the students place the paper with the many dots to the floor, preferably a significant way out of the middle of the three dots A, B & C and fix it there, e.g. by tape.
3. If the distances are already measured go to step 4. If not choose three to six students to move out of the area. The rest of the students choose together one dot (let's call it point P) and give three students a tape measure to measure the distances to the nearest mm from that dot to A, B and C, so there will be three distances A-P, B-P and C-P. Note these distances somewhere clearly visible.
4. Call the students which where away back and give them the measurement tapes, the ropes and the scissors. Let them cut ropes with a length equal to the indicated distances. Tell them which length belongs to which distance measurement (A-P, B-P and C-P), and let them figure out which dot was chosen.

Step 3 & 4 could be repeated if there is enough time.

5. A discussion of the importance of time accuracy should follow – each GNSS satellite is equipped with an atomic clock which measures time with great accuracy. However, the receiver doesn't contain an atomic clock, so how can accurate 'travel time' measurements be made? Answer: in order to have a good timing accuracy a fourth satellite is used so that you can do four trilateration calculations (one with satellite A,B and C, a second one with satellites A,B and D, a third one with satellites A,C and D and the fourth with satellite B,C and D). The exact time of the arrival of the signals is adjusted to make sure that all 4

trilateration experiments come up with the same solution. In this way, you synchronise your local receiver clock with the GNSS system.

6. If time permits you can introduce some uncertainty. Ask each three students to either add or subtract 20 mm from the original given distance and cut a rope with the new length. With these new lengths they should try to find a new point where all ropes meet and indicate this on the paper and measure the distance to the original point. They can repeat this by using other ropes that are 20mm longer or shorter to determine the area of uncertainty.
7. Discuss the risks of this uncertainty and if time permits also where this uncertainty might come from.

Discussion of the uses of GNSS (15 min)

a: Discussion of the general uses of GNSS (7-8 minutes)

Discuss with the class the uses of GNSS.

GNSS applications generally fall into 5 major categories:

1. Location – determining a position
2. Navigation – getting from one location to another
3. Tracking – monitoring object or personal movement
4. Mapping – creating maps of the world
5. Timing – bringing precise timing to the world

b: Discussion of the timing uses of GNSS (7-8 minutes)

Discuss in the same group further about the importance of accurate timing, where will it be used for (5 minutes) and let one student from each group present the outcome of this discussion (2 minutes).

Uses are:

1. Banking transactions (including ATM's)
2. Electricity grid synchronization of the changing voltage
3. Communication systems
4. Synchronized timing of scientific instruments
5. Film business (Hollywood studios are incorporating GPS in their movie slates, allowing for unparalleled control of audio and video data, as well as multi-camera sequencing.)

Working for Galileo (5 min)

Show movie of person working for Galileo coming from a vocational school.

4. Extension

Hide an "treasure" somewhere outside and do a treasure hunt by giving distances from 3 (or more if you add some errors) fixed points.

5. Annex

Background information

The following video explains how GPS works and what the most important sources of errors are:

1) How does GPS system work? - YouTube or
2) How does GPS work? - YouTube

This video could be watched before, during or after the trilateration activity as a further source of information about GPS: https://www.youtube.com/watch?v=IoRQiNFzT0k

A webpage with all kinds of applications of GNSS:
GPS.gov: Applications

Information to the teachers

Paper with dots (add a link to this)

VET Schools

All kinds of VET schools could do this activity.