Mobile Mapping Technology

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AGH, WGGiIŚ

Plan wykładu

1. IMMS
2. GNSS
2. INS

1. IMMS

Calibration of the immersive mobile mapping system (IMMS)

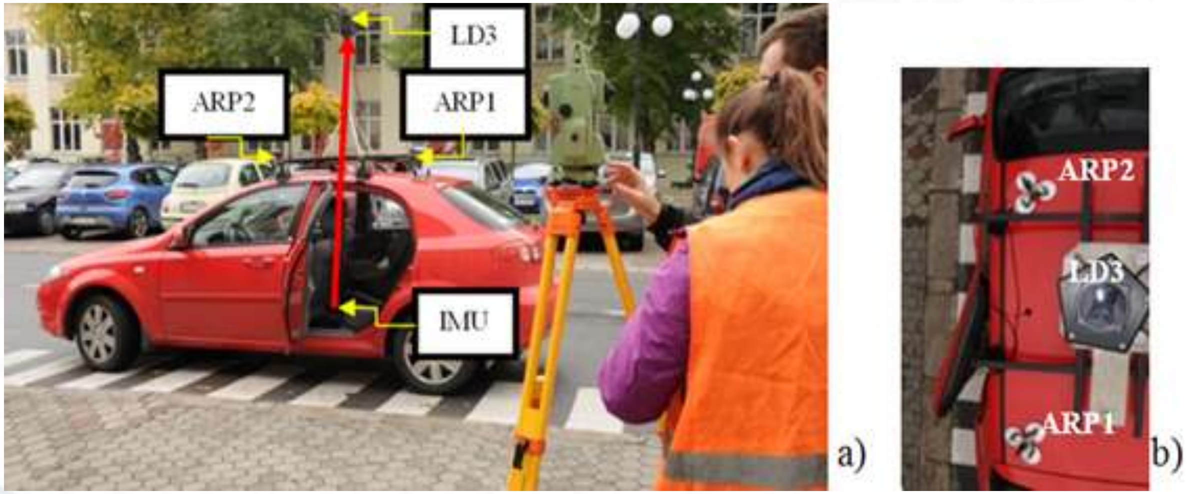
Ladybug 3

ProPak 6
(Novatel)

SPAN A1
(Novatel)

2 antennas GNSS

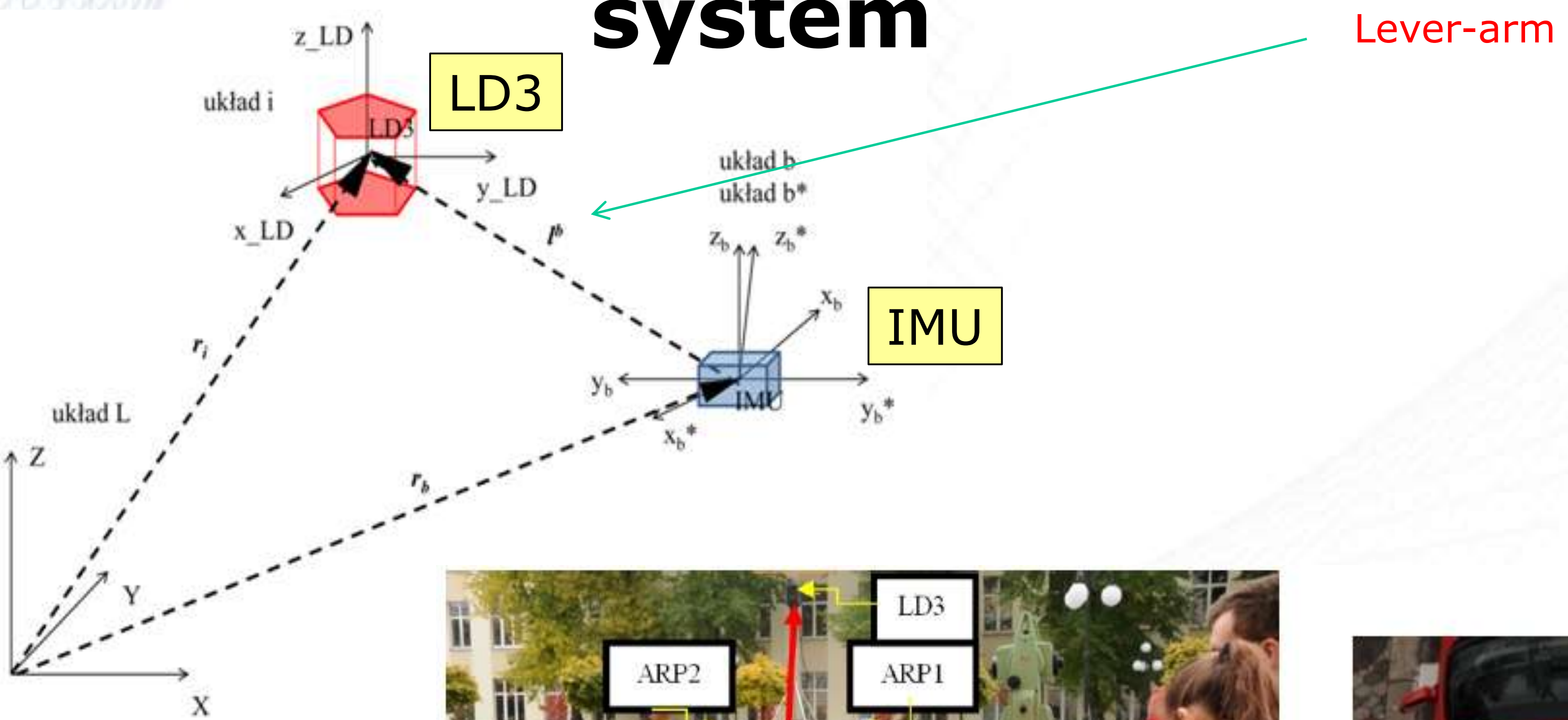
Lever arm

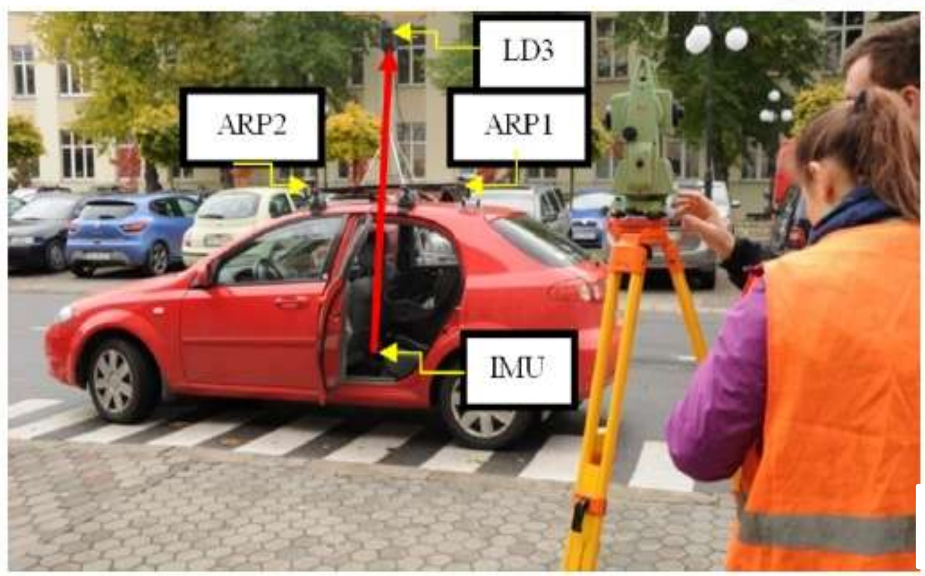


No laser scanner

Calibration of the immersive mobile mapping system

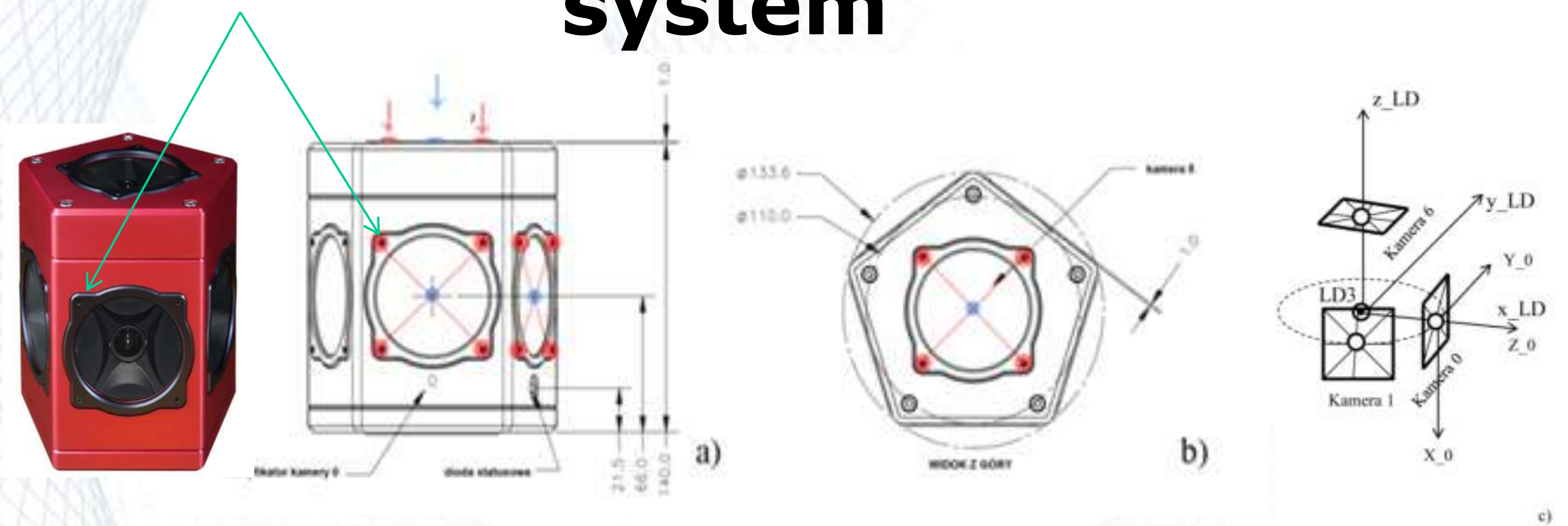
Immersive mobile mapping system

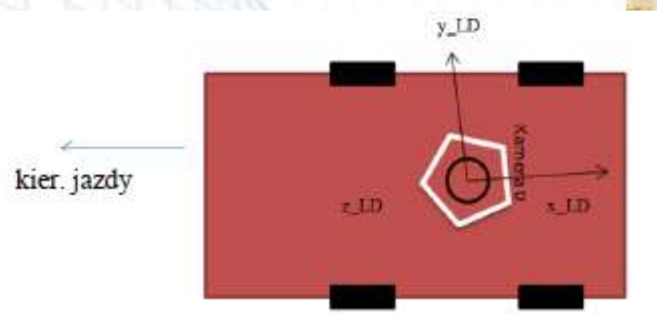




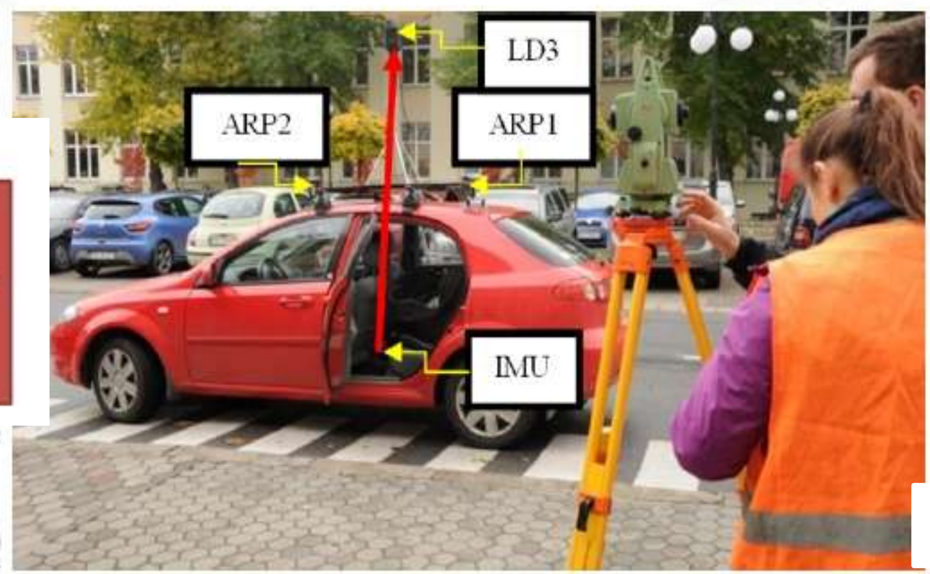
Immersive mobile mapping system

LD3





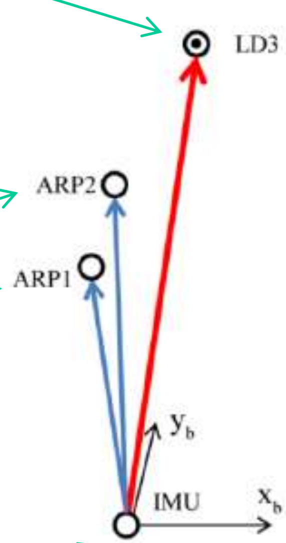
View from the top
- LD3's coordinate system



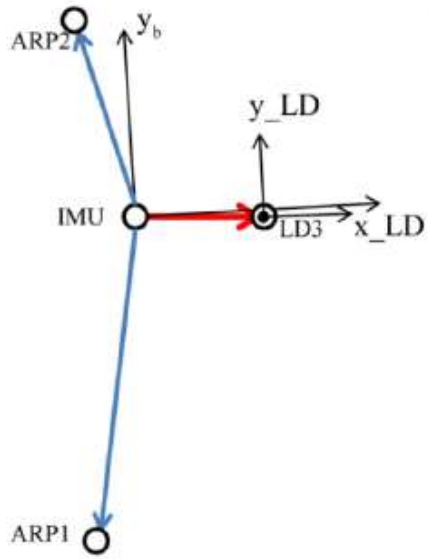
Immersive mobile mapping system (IMMS)

IMU

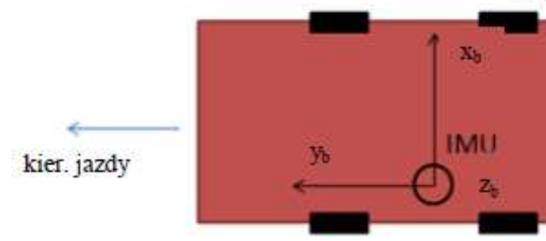
Lever-arm



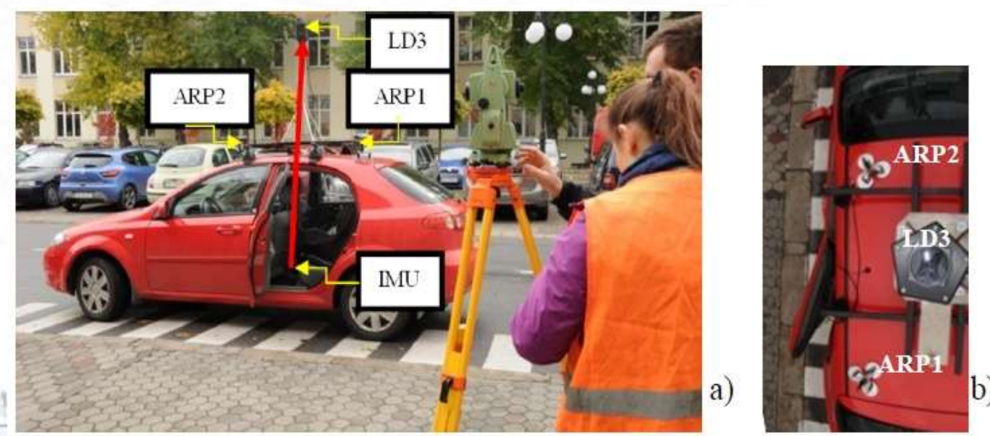
View in the direction of movement



View from the top



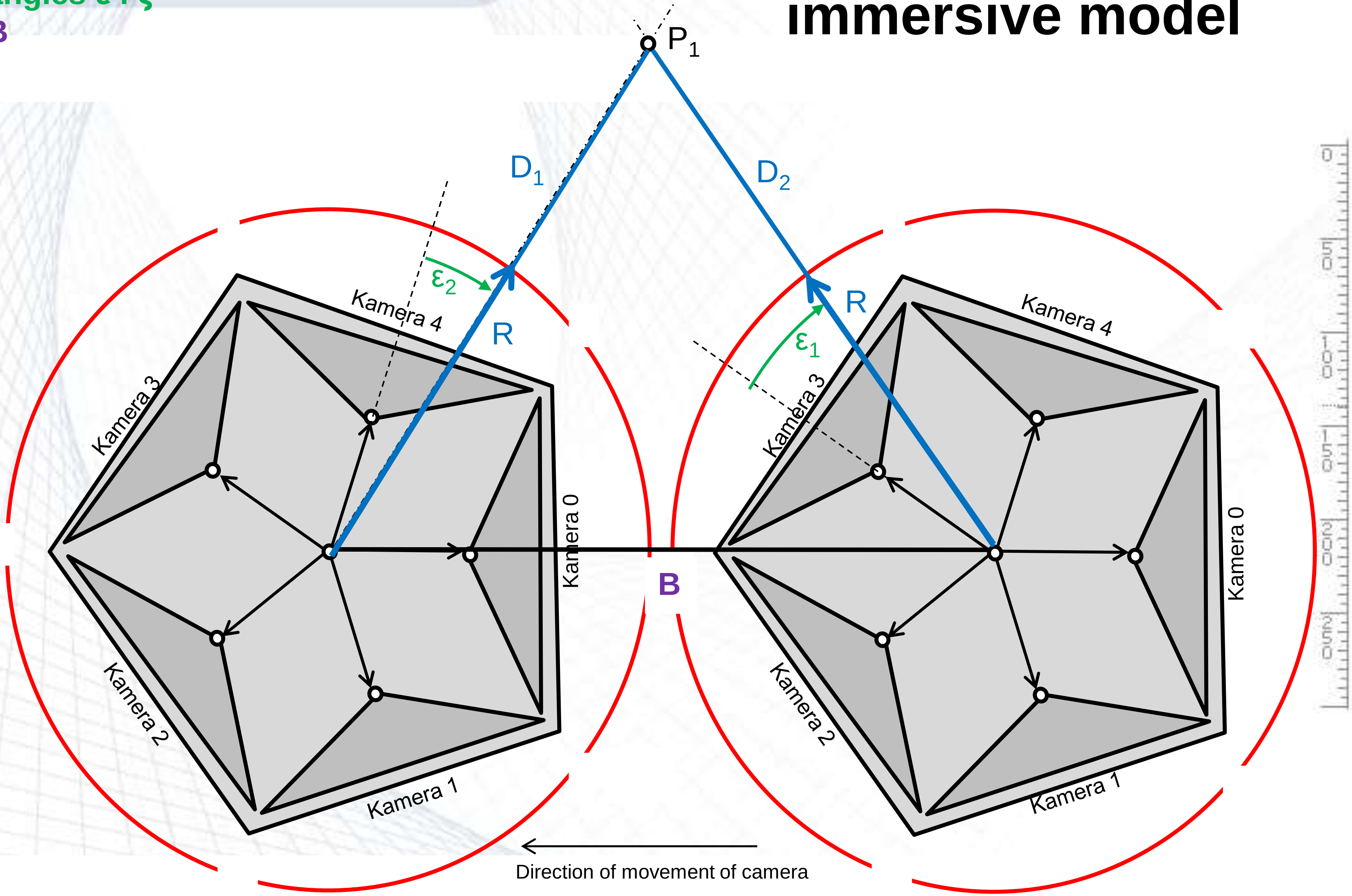
View from the top
- IMU's coordinate system



Accuracy in immersive model

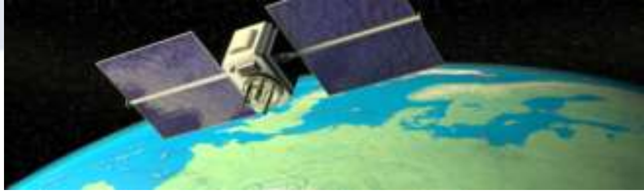
Accuracy depends on:

- choise of R i D
- angles ε i ξ
- B

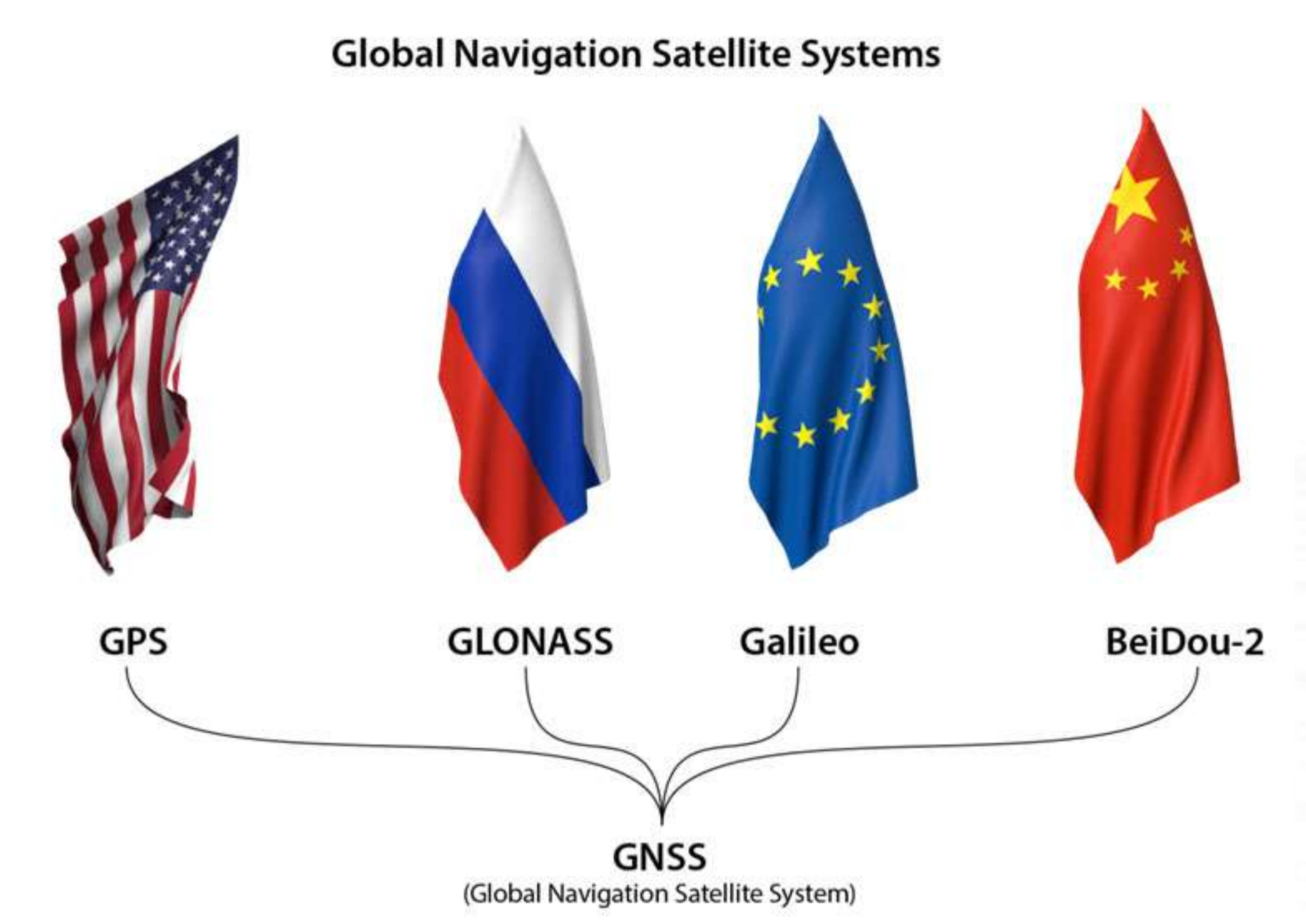


[Kwiatek 2018]

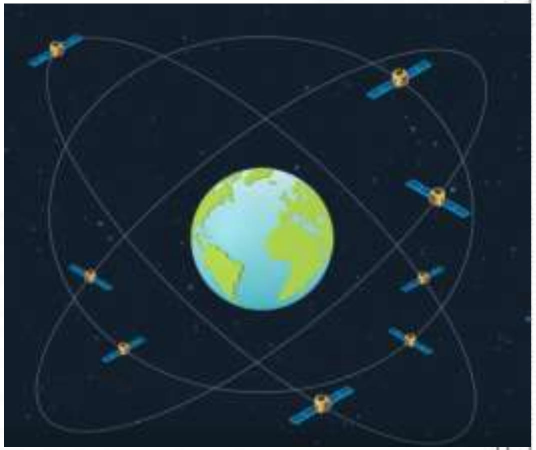
2. GNSS



GNSS

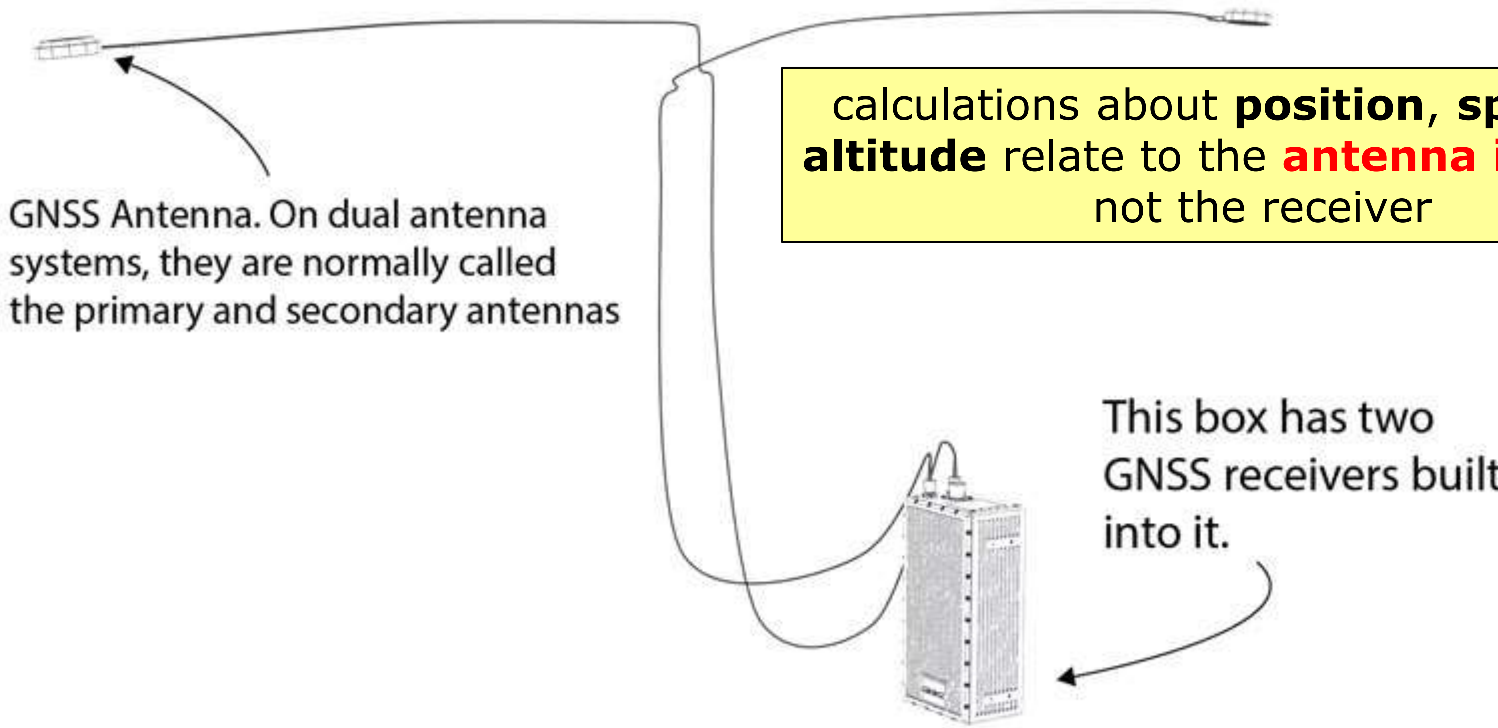


Global Navigation Satellite Systems
GPS
GLONASS
Galileo
BeiDou-2
GNSS
(Global Navigation Satellite System)

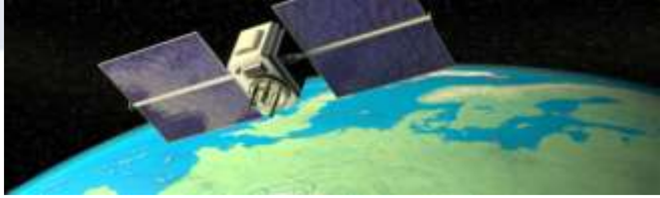


GNSS receiver

calculations about **position**, **speed** and **altitude** relate to the **antenna itself**, and not the receiver

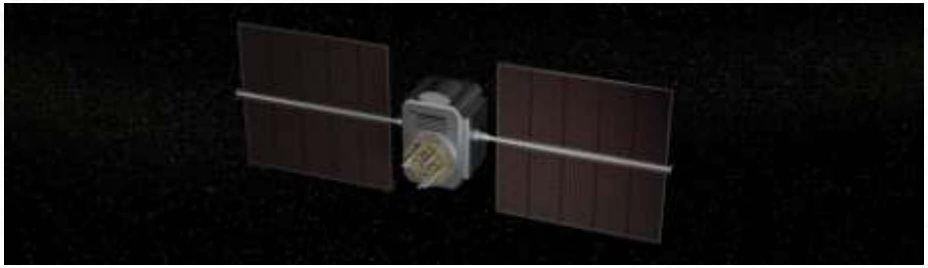


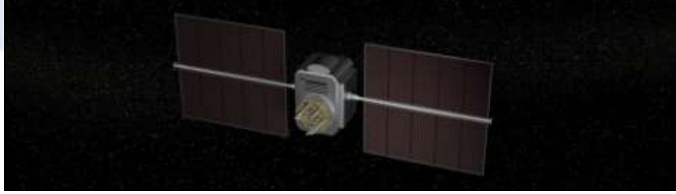
Although the GNSS receivers do all the work, the actual measurements they produce relate to the position of the antennas themselves. This is important to bear in mind, because the length of the antenna cables means a receiver can sometimes be quite a distance from the output position measurements. On sat navs and everyday GPS products, this doesn't matter as they are rarely capable of accuracy greater than several metres anyway.



GNSS

- The space segment
- The control segment
- The user segment



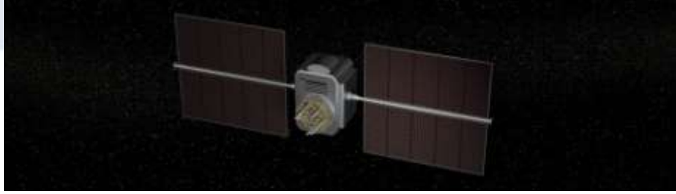


The space segment

The space segment is concerned with the satellites in orbit.

In 2015 the GPS constellation consists of **32 non-geostationary satellites** in medium Earth orbit, although not all satellites are active.

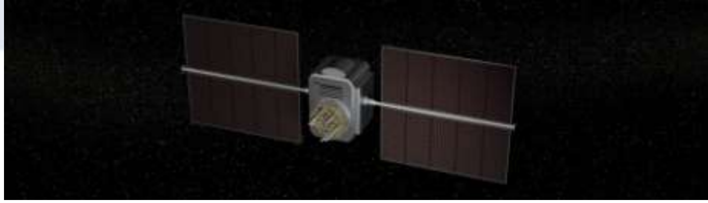
Each satellite orbits once every 11 hours, 58 minutes and 2 seconds at an average altitude of **20200 km** (that’s an orbital radius of 26571 km).



The space segment

The GPS satellite constellation is arranged into **six equally-spaced orbital planes**, with no fewer than four satellites in each plane.

This arrangement ensures a minimum of four satellites can be seen **15°** above the horizon at almost any time, from any point on the planet—although in reality there are generally more.

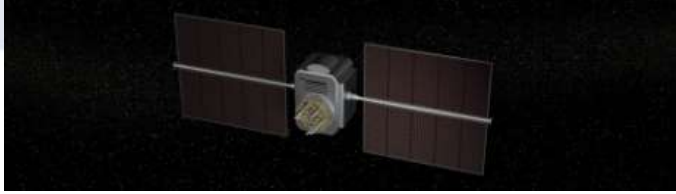


The space segment

While satellites vary in age and design, their principal of operation remains the same.

Each one contains **four highly accurate clocks** with a fundamental frequency of **10.23 MHz**, and they and constantly transmit two carrier waves in the L-Band that travel back to earth at the speed of light.

These carrier waves are referred to as **L1** and **L2**.



The space segment

• The **L1** carrier has a frequency of **1575.42 MHz** (10.23 MHz × 154 = 1575.42 MHz).
• The **L2** carrier has a frequency of **1227.60 MHz** (10.23 MHz × 120 = 1227.60 MHz).

The carrier waves are important because they **bring the information from the satellite back to earth**, and it’s that information that allows our receiver to work out where we are.

The control segment

The control segment refers to a number of **ground stations situated around the globe** (close to the equator) that are used to **track**, **control** and **send information** to each of the GPS satellites.

This is an important role as it is vital the clocks in each satellite are **synchronised**—because the whole system relies on timing.

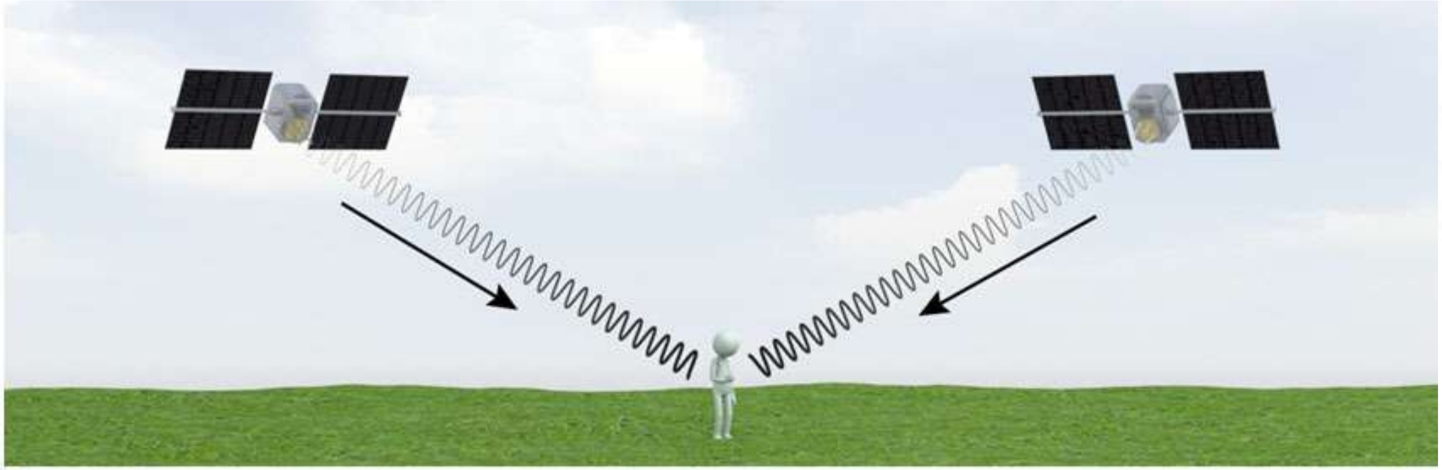
The control segment

The **orbit information** that is sent up to each satellite is vital too, because we need it in order to work out where the satellite was when the information was sent.

All of this information is sent up to the satellites, then carried **to your GPS receiver** within the **L1 carrier wave navigation message**.

The user segment

The **GNSS receiver** on the vehicle is receiving signals from the satellites and working out **where it is**.



GPS products are completely passive. They only receive signals, they do not transmit anything.

The user segment

A **GPS receiver** can only make use of signals from the **GPS satellites**, while a **GLONASS receiver** can only use signals from **GLONASS satellites**.

There is another kind of receiver that can actually take signals from both types of satellites though (**GPS and GLONASS**), to augment its measurements.

GPS receiver

The short and over simplified answer to **how a GPS receiver works out where you are is**:

- It calculates **how long** it takes the signal from each satellite it can see to arrive.
- It multiplies that time by the speed of light to calculate the **distance** to each satellite.
- It then calculates its **position** relative to no fewer than three satellites using trilateration.
- Because the **receiver knows the precise position of each satellite** when the signal was sent, it can translate its own relative position into an Earth-based co-ordinate system.

GPS signal

The unique signal transmitted from each satellite contains two codes and a message:

- **C/A code** (coarse/acquisition code)
- **P code** (precision code) [called Y code in its encrypted form]
- **Navigation message**

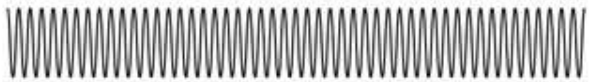
GPS signal

The **P code** is encrypted for military use, and so can be ignored.

It's encrypted to stop spoofing and to control who has access to the system.

Incidentally, once the P code has been encrypted, it's referred to as **Y code**.

The GPS signal



Carrier wave

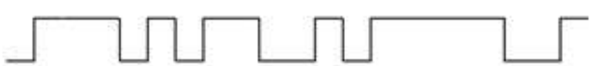
Two carrier waves are used:
L1 = 1575.42 MHz
L2 = 1227.60 MHz

C/A code

Each satellite modulates its own unique codes onto the carrier waves. The C/A code that civilians can access is sent on L1. It is made up of 1,023 bits. The entire code takes one millisecond to transmit and repeats endlessly.

Navigation message

As well as the C/A code, a navigation message is also modulated onto the L1 carrier. This message contains lots of vital information and is quite long. However, because of the relatively slow rate that it is sent, it takes 12.5 minutes to send one complete message.



P Code

A second unique code is modulated onto both the L1 and L2 carriers. This code is encrypted for military use and cannot be used by civilians. It contains many more bits and is sent at a higher speed, which allows authorised users to calculate position accuracy with much greater accuracy.

Binary string

0100101001

Two copies written on tracing paper

| 0100101001   0100101001 |

←

No match

| 0100101000101001 |

Sequence matches in this position

| 0100101001101001 |

Sequence also matches in this position

| 0100101001 |

C/A code is constructed so that the sequence only matches in one postion

1011110001011111111100010000000000001000001000000111110000000010000010000000111110000

1011110001011111111100010000000000001000001000000111110000000010000010000000111110000

←

GPS signal

The **C/A code** each satellite transmits is **unique** to that satellite.

Navigation message contains data. It takes **12.5 minutes** to send the whole message.

GPS signal

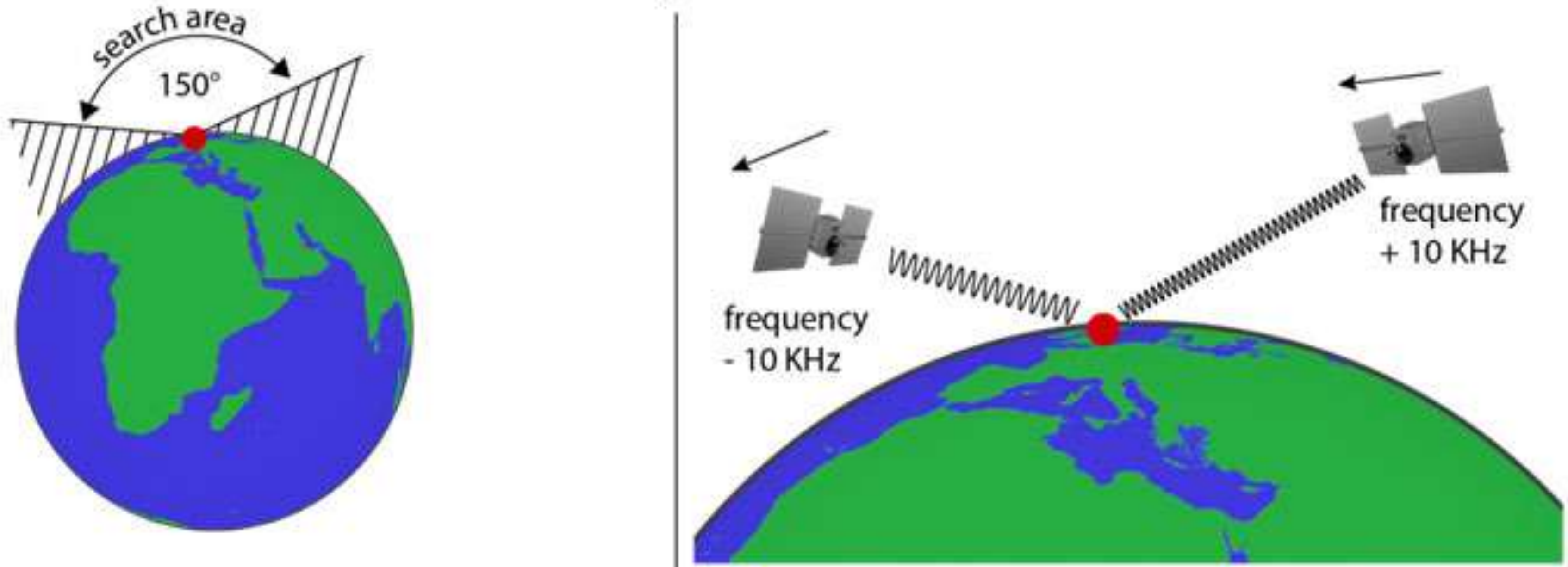
Each satellite transmits two frequencies—
L1 at 1575.42 MHz
and
L2 at 1227.60 MHz.

All three elements (the **C/A code**, **Y code** and **navigation message**) are modulated onto the **L1 carrier**, while only the Y code is modulated onto the **L2 carrier**.

We can make use of the **L2 carrier** wave itself (differential corrections).

Finding satellites

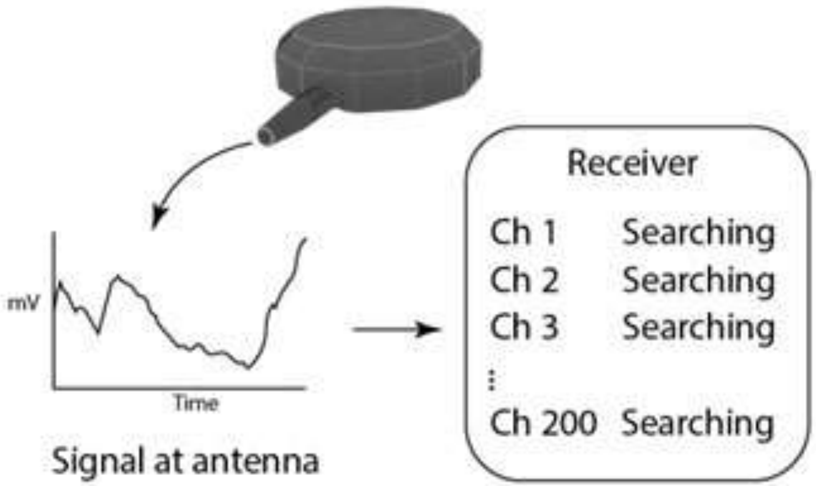
Searching for satellites



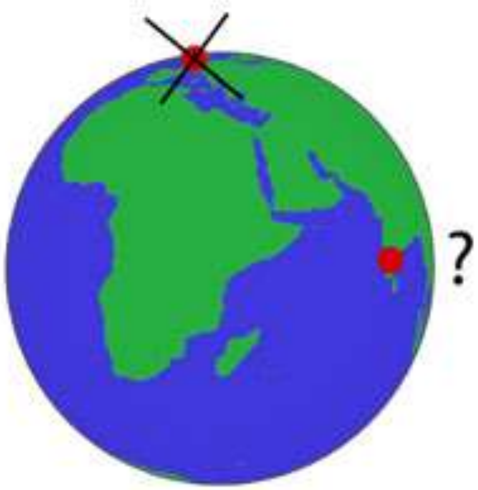
1. When the receiver is powered up, it uses the current time, its last known position and the almanac data to work out which satellites is should be able to see. It searches an area of sky 15° above the horizon. Almanac data is valid for about 6 months without being updated.

2. Almanac data also gives the some idea about how the satellites are moving relative to the receiver's assumed location. This allows it to guess at how Doppler shift will affect the frequency of each satellite's signal. The L1 frequency of 1575.42 MHz can shift by as much as 10 KHz.

Finding satellites



3. Most receivers have a large number of channels. Each channel searches for a signal. If it doesn't find one, it tries some new parameters. More channels reduces the time required to lock on to the frequency, phase and code from a given satellite. Once locked, channels can be used to search for other satellites.



4. If the receiver has moved significantly since it last produced a valid position measurement, it will take longer to lock on as it will be looking for satellites that are not there. Equally, if the almanac is out of date a new copy will need to be captured. It takes 12.5 minutes to do this, but first a satellite must be found to receive from.

Working out the range to a satellite

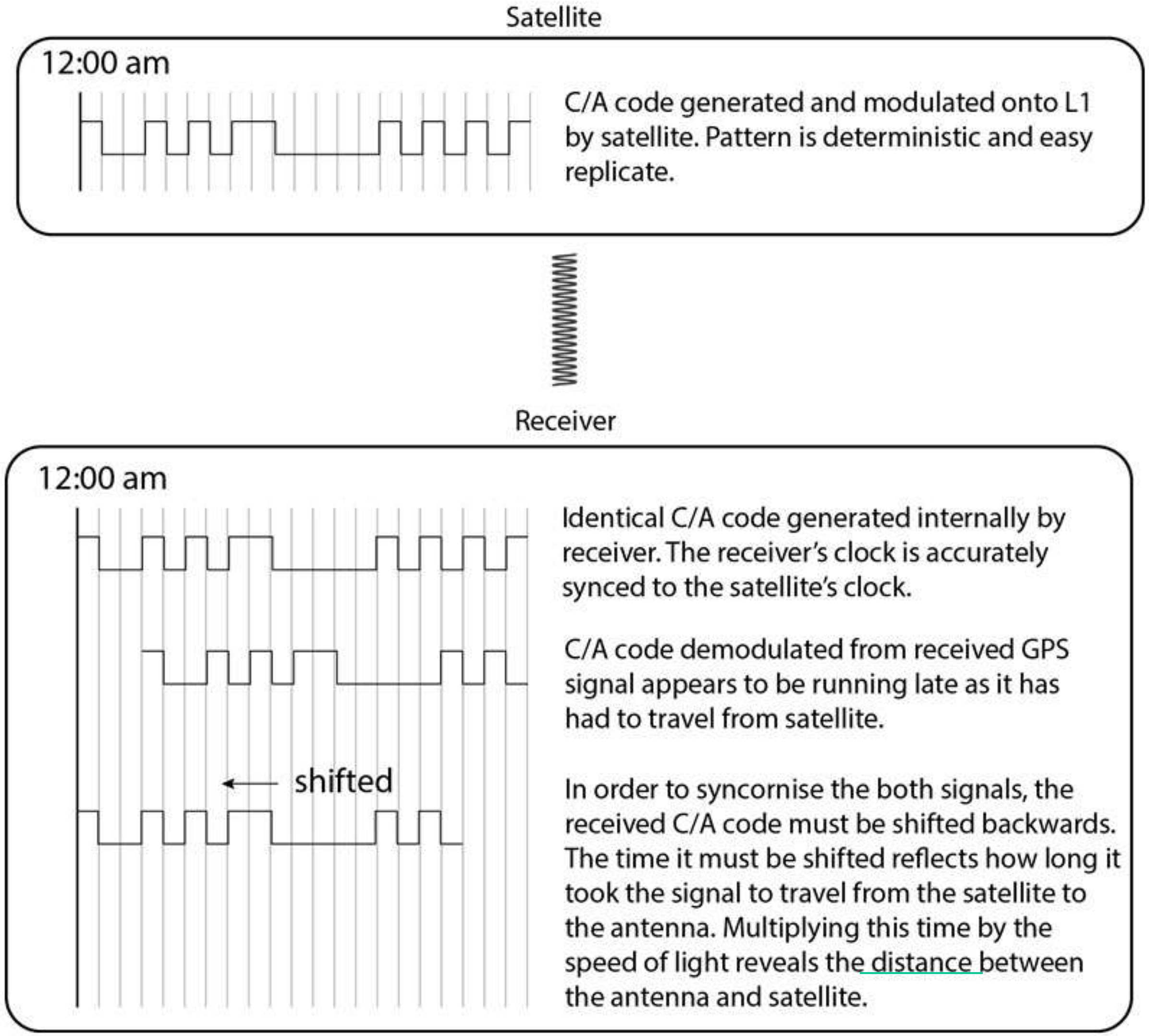
Each satellite in the GPS constellation transmits a **unique C/A code**.

GPS receiver has the ability to generate exactly the same sequence of code as the satellite itself.

By generating the same pattern internally, the **receiver looks for the pattern** being transmitted by the satellite, then works out **how much of a delay** there is compared to its own pattern.

It can do this because of the accurate **clock synchronisation**.

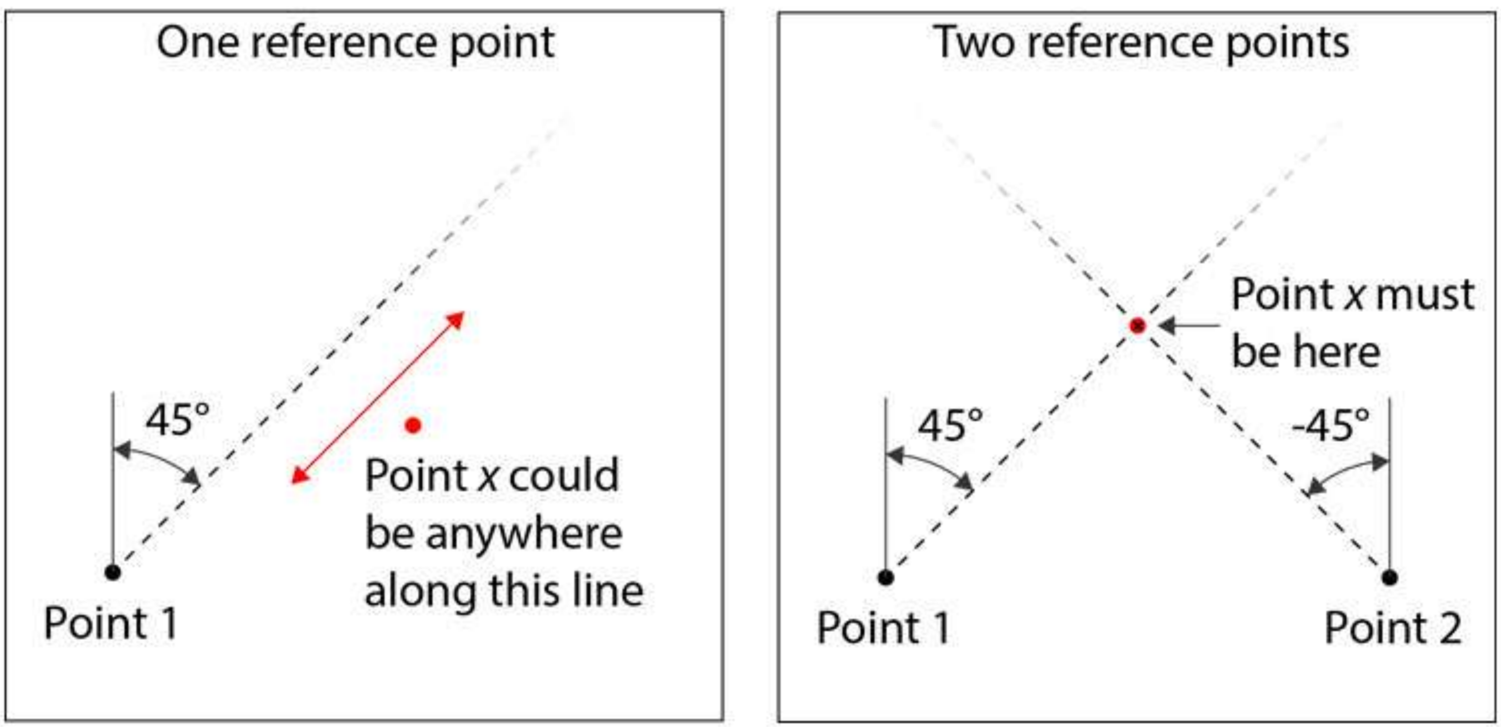
Working out the range



Triangulation

Triangulation

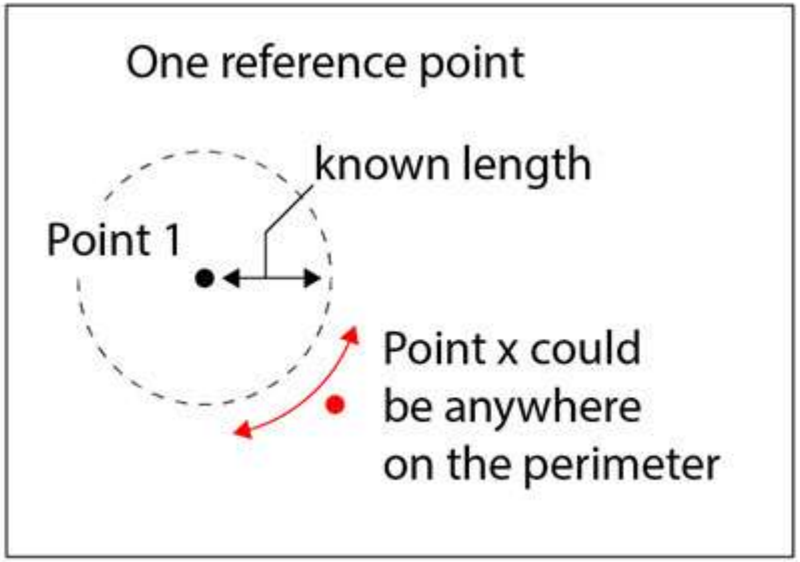
Triangulation projects lines of unknown length along known angles to find a point. As long as there is more than one reference point we can identify the location of a new point. So, if we know point *x* is located at angle of 45° from point 1, and at an -45° from known point 2, the point at which those projected lines intersect must be the location of point *x*.

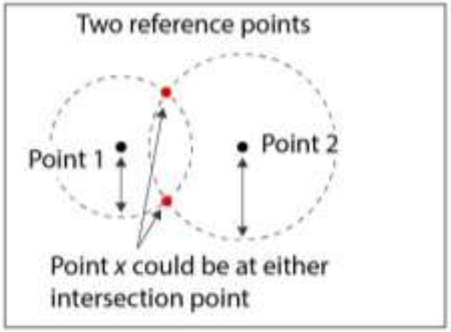


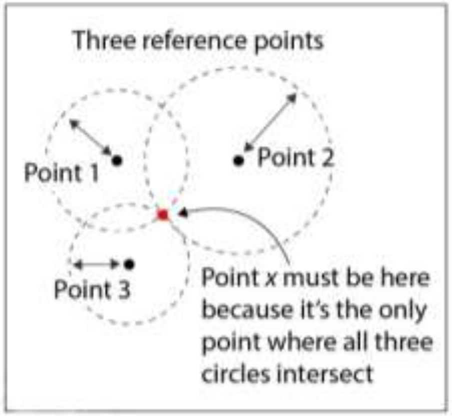
Trilateration

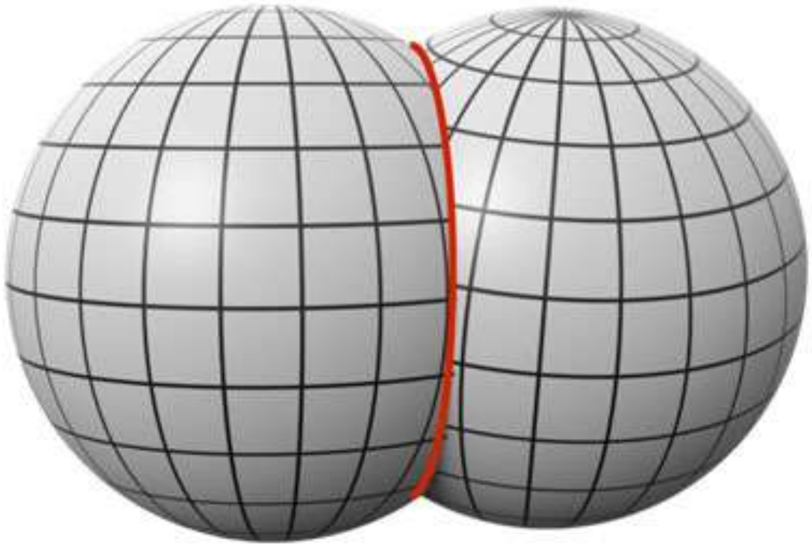
Trilateration

Trilateration uses lines of known length but unknown angle (circles in other words) to find a point. As long as there are more than two reference points we can identify the location of a new point.
So, if we know point *x* is 1 metre from point 1, 1.5 meters from point 2 and 0.75 meters from point 3, the point at which those circles intersect must be the location of point *x*.

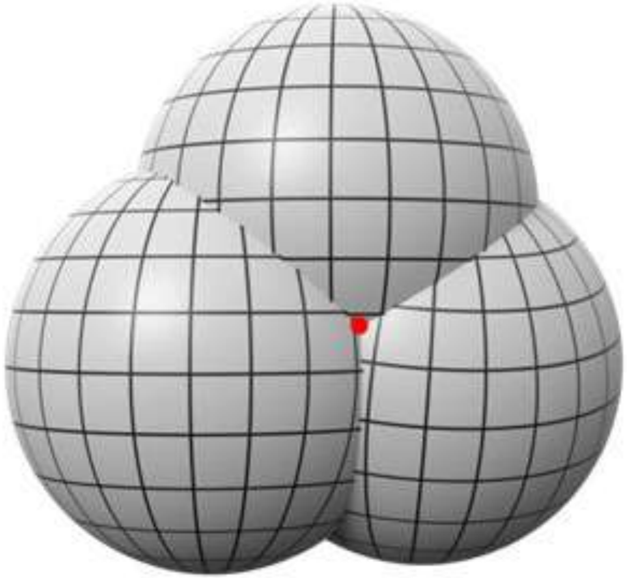








When two spheres intersect, the interestion creates a circle (red).



When three spheres intersect, there are only two points common to all three spheres (one each side).

SPS

Standard Positioning Service, and describes GPS position measurements that are based only on the **C/A code**.

SPS provides the **lowest accuracy GPS position measurements**, normally in the region of **3–10 metres**.

To make SPS measurements the GPS receiver locks onto four or more satellites, and then uses the C/A code to **estimate the distance** to each satellite. These estimates are called **pseudo-range measurements**.

DGPS

The receiver has no way of actually knowing how the **speed of the satellite signal** has been affected as it passed through the **ionosphere**.

The only way to allow for this is to **measure, rather than estimate**, how the signal speed is being affected as it makes its way down through the atmosphere.

A separate GPS receiver (called a **base-station**) is placed at a pre-surveyed point and turned on. Because the location of the base-station is already known with great accuracy, the base station is able to **compare the position measurement generated by its own GPS receiver with the known co-ordinates**. Any difference means they signal from one of more satellites is being delayed. All the system has to do then is work out **how much correction** should be applied to each satellite in order to correct the GPS position measurement.

Position measurements
40cm

RTK

RTK stands for **Real Time Kinematic**, and is another technique that improves the accuracy of GPS position measurements.

RTK float - decimetre level accuracy

RTK integer - centimetre level accuracy

The code is sent at a rate of **1.023 Mb/s**, which means one bit is sent about every microsecond. In one microsecond the radio signal from the satellite covers a distance of about **300 metres**.

The carrier wave that the **C/A code** is modulated onto is at a much higher frequency however—1575.42 MHz. This means a single wave covers about **19 cm**.

Pros and cons of GNSS

- easy to use
- don’t drift and can achieve high-levels of accuracy
- need a clear and uninterrupted view of the sky

GPS receiver is great at capturing **position** and **velocity** measurements it’s not much good if you’re also interested in **roll, pitch and yaw**.

A dual-antenna system helps solve some of those problems, but still doesn’t provide a complete picture.

3. INS

GPS/INS

GPS receiver - after a short time it will generate a position measurement.

It says '*you are at this latitude and this longitude*'.

It gives us an **absolute position** using a **known co-ordinate system**.

INS - the measurement they generate is **relative to their last known position**

After an inertial navigation system has been turned on for several minutes, it can't say '*you are at this latitude and this longitude*', but what it can say is, '*you haven't moved from where you started*'.

If you tell the INS **where it started**, it can easily work out **where it is now**, based on its own measurements.

How does an INS actually work?

1. **IMU** (inertial measurement unit) - the **accelerometers** and **gyros** that provide **acceleration** and **angular velocity** measurements

2. The **navigation computer** takes measurements from the IMU and uses them to calculate the relative **position, orientation and velocity** of the INS

How does an INS actually work?

Two kinds of navigation computers in use:
•**stabilised platforms**
•**strapdown navigators**

Stabilised platforms use real, spinning mechanical gyroscopes to stabilise a platform that rotates independently to the INS.

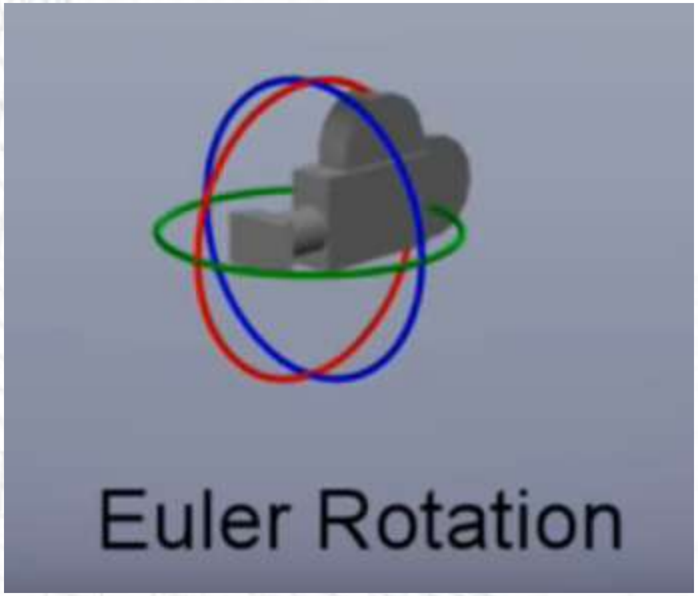
How does an INS actually work?

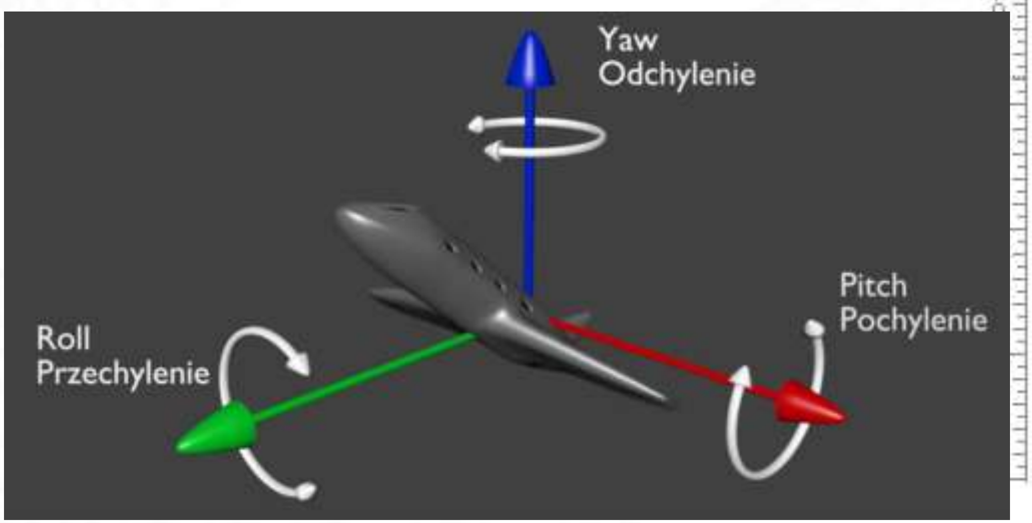
Strapdown navigator do not move independently of the INS

Mechanical gyros inside a stabilised platform, the gyros used inside a strapdown navigator are typically **MEMS** (microelctromechanical systems), <u>which don't appear to have any moving parts</u>.

angular rate sensors

Yaw Pitch Roll



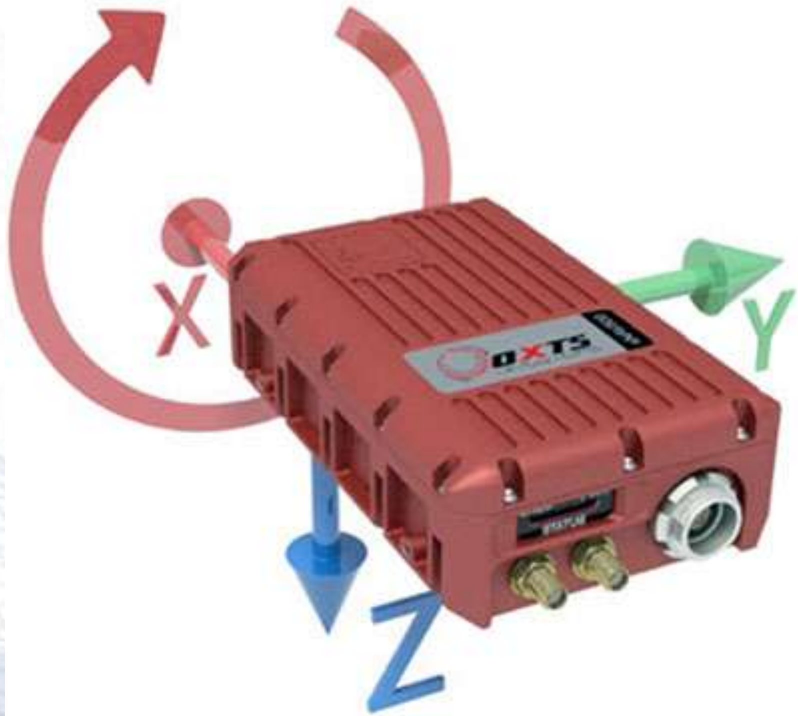


How does an INS actually work?

In order to capture the measurements needed for navigating in 3D space, the **axes** of the inertial sensors are laid out in a mutually **perpendicular way**.

In other words, **each axis is at 90° to the other two**

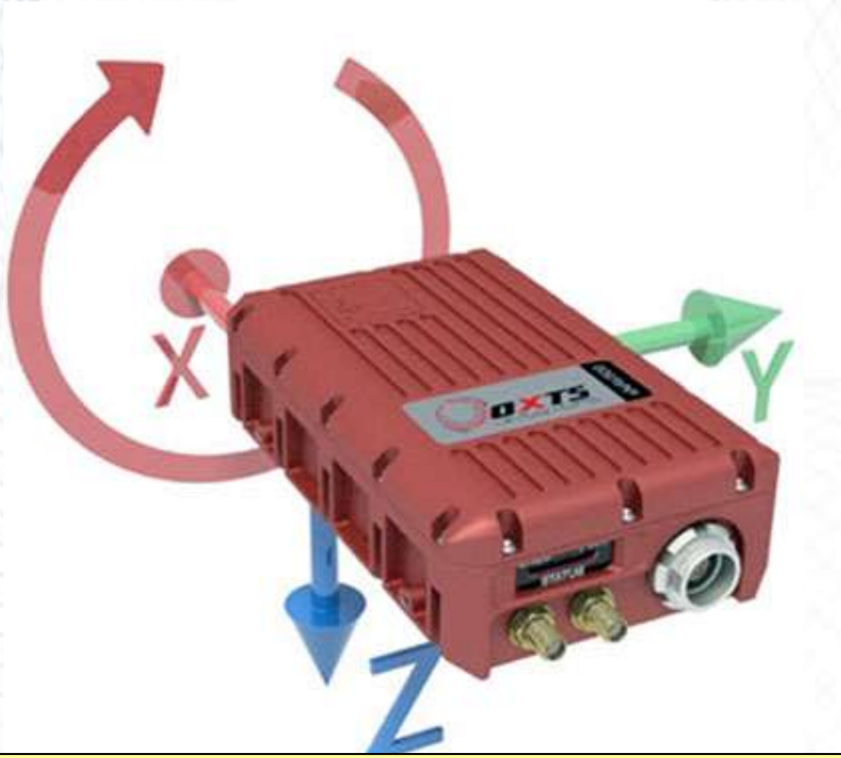
positive reading on the x-axis gyro

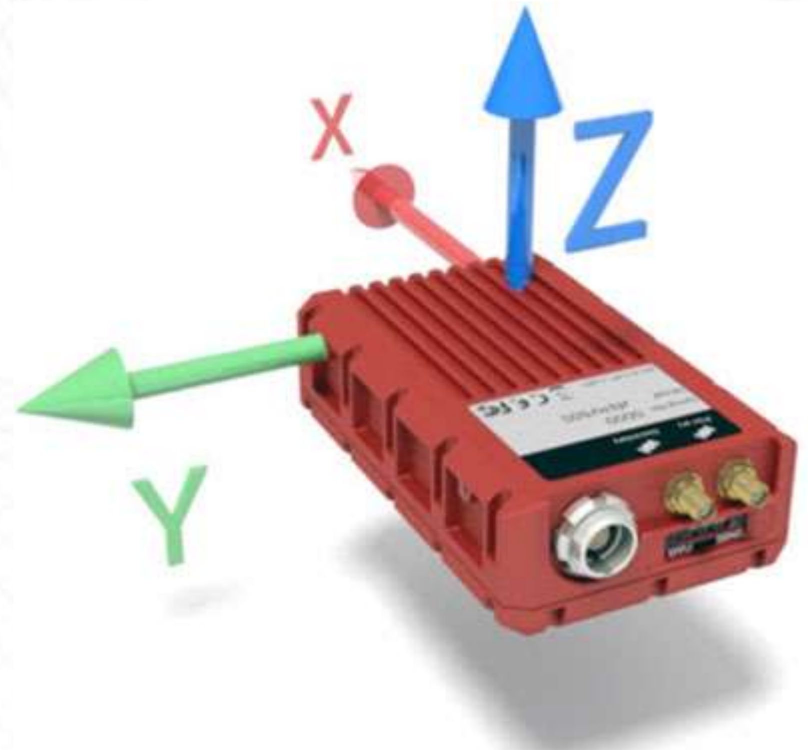


Positive/negative

Frames of reference

Taking measurements along (and about) the x-, y- and z-axes, the navigation computer can understand how it is moving and rotating.





INS accelerates down, the z-axis would register a positivre value

INS accelerates down, the z-axis would register a negative value

Different frames of reference

Accelerometers

They measure **acceleration**, not velocity.

1 m/s² means that for each additional second that passes, an **object's velocity will increase by an additional 1 m/s**

Inertial navigation system doesn't directly measure velocity, by keeping track of **how much acceleration** there is, and **how long it lasts**, the INS can easily work out what the velocity is by multiplying the acceleration by time.

Three accelerometers:

- **measure acceleration in 3D space** and **calculate the distance** travelled as well as **current velocity**.

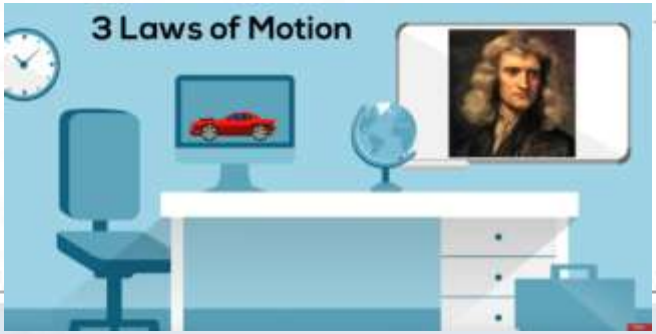
Proper acceleration

Sir Isaac Newton

laws of motion

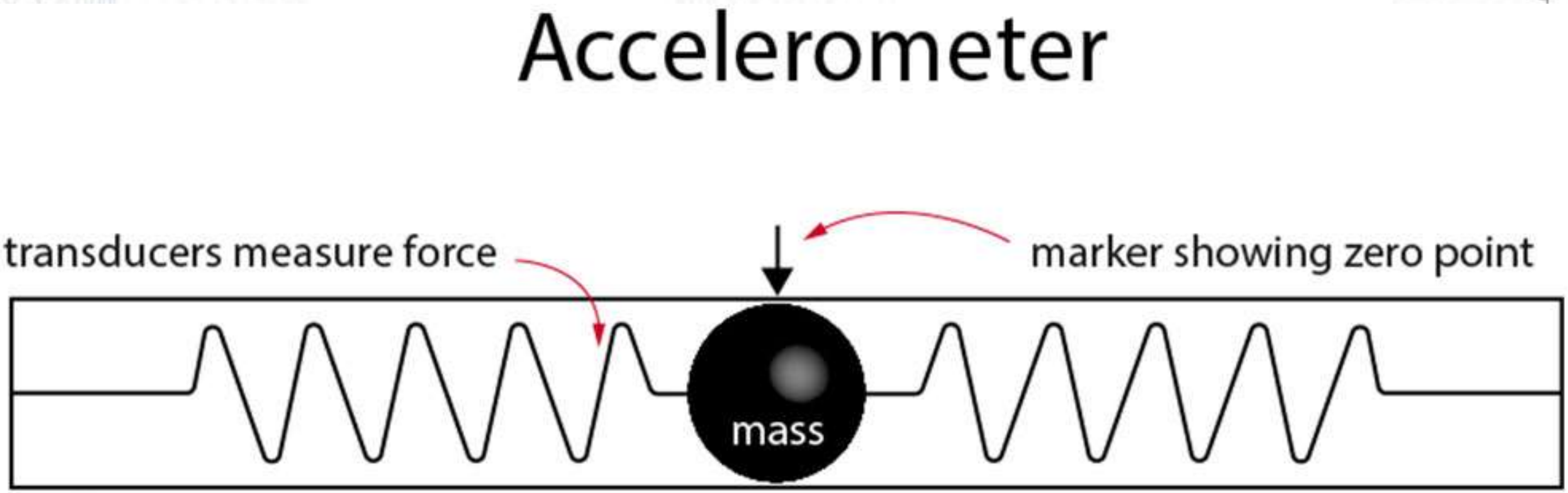
Newton's first rule tells us that unless some force acts on an object, it will stay perfectly still, or carry on moving at the same speed. In other words, to get something moving, or to change its speed, we need to apply a force.

His second rule describes how an object's acceleration is related to the force acting on it, and the mass of the object. It can be summed up as force = mass × acceleration (F = ma).



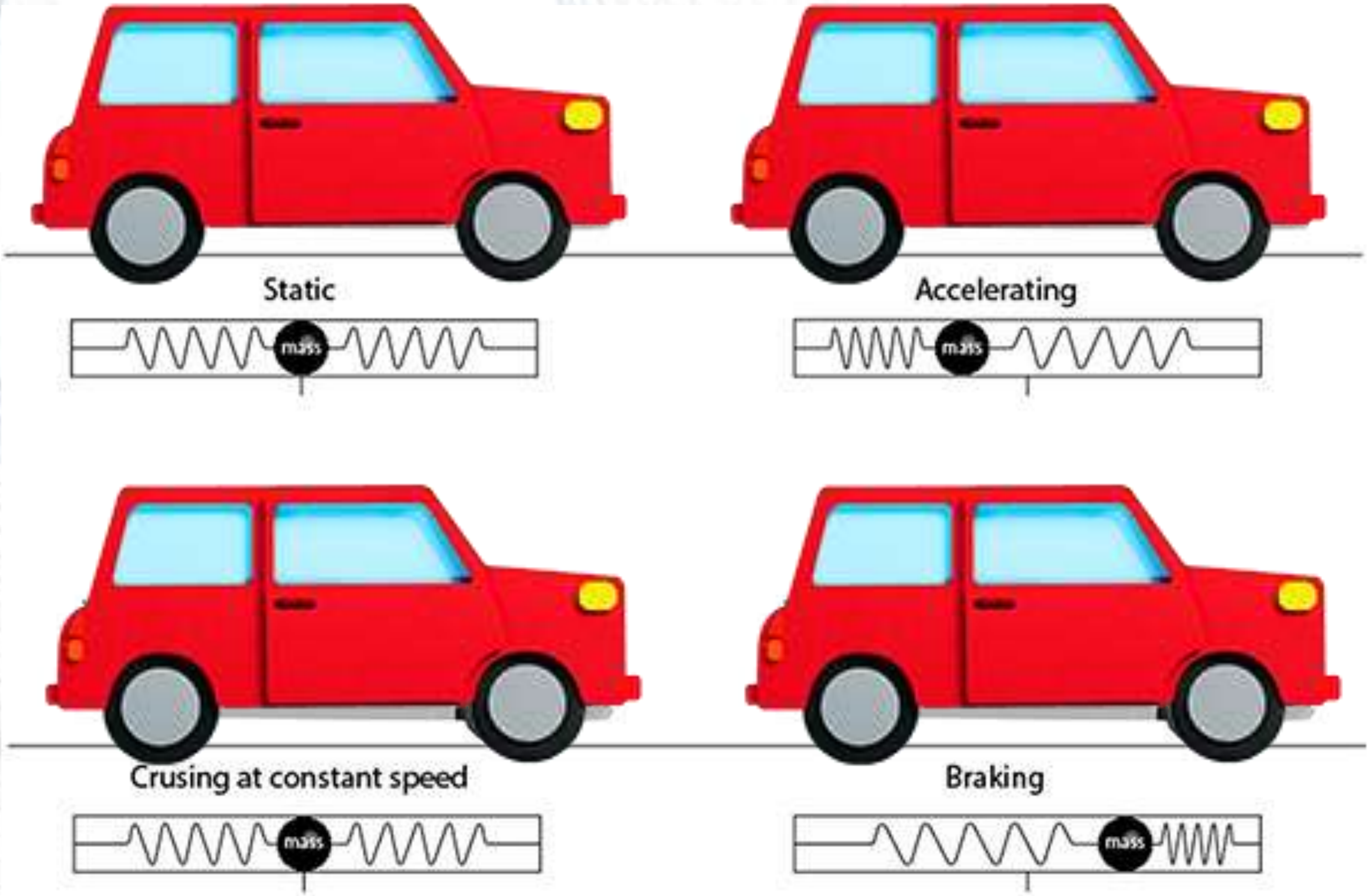
Proper acceleration

Accelerometers **measure acceleration** relative to freefall using the principal described in **Newton's second law of motion**.



From the above image we can see the accelerometer contains **a known mass**, which is attached to **a transducer capable of measuring force**. However, do note that the mass is constrained within the casing of the accelerometer and can only move left or right—this defines the accelerometer's measurement axis.

Proper acceleration

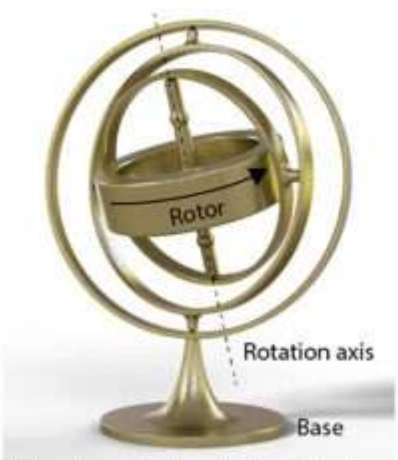


When the car **accelerates and brakes** however, the **mass moves.**

Gyros

Accelerometers are great at **measuring straight line motion**, but they're **no good at rotation**.

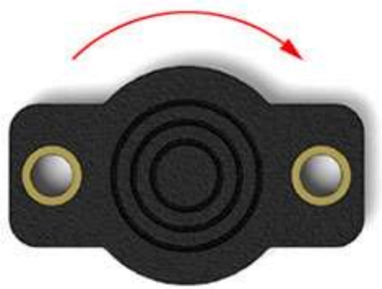
Gyroscope employs one or more spinning rotors held in a **gimbal** or suspended in some other system that is designed to isolate it from external torque (pl. *moment obrotowy*).



When the rotor is spinning, the base can be moved and rotated in any way and the rotor will try and keep its rotation axis in the same orientation.

Because the gyro's rotor wants to maintain its initial axis of rotation, **sensors can be mounted to the gimbal to measure the relative change in orientation of the external frame** to which it is attached.

MEMS angular rate sensor



MEMS (microelectromechanical system) gyros come in many shapes and sizes. The measurement axis of this angular rate sensor is shown by the red arrow. Rotation in the direction of the arrow gives a positive value while the opposite direction gives a negative measurement. Linear movement isn't registered.

Angular rate sensors (gyros) measure angular rate in °/s (degrees per second). They do not "measure" direction, although you can use their measurements to work out what direction the sensor is facing if you know which way it was facing to begin with. This sensor and the one to the left would both read 0 °/s.

This sensor is rotating to the right and would produce a positive value. The measurement output depends on how fast it is rotating—the higher the number, the faster the rotation. If the sensor saw an average value of 90 °/s for 0.5 seconds, we could work out that the sensor had rotated 45° clockwise.

By mounting three gyros on three mutually perpendicular axes it's possible to keep track of an object's orientation in 3D space. When combined with accelerometers it's possible to track the relative position, orientation and velocity of an object—and as long as we know the start position, we can work out the current position.

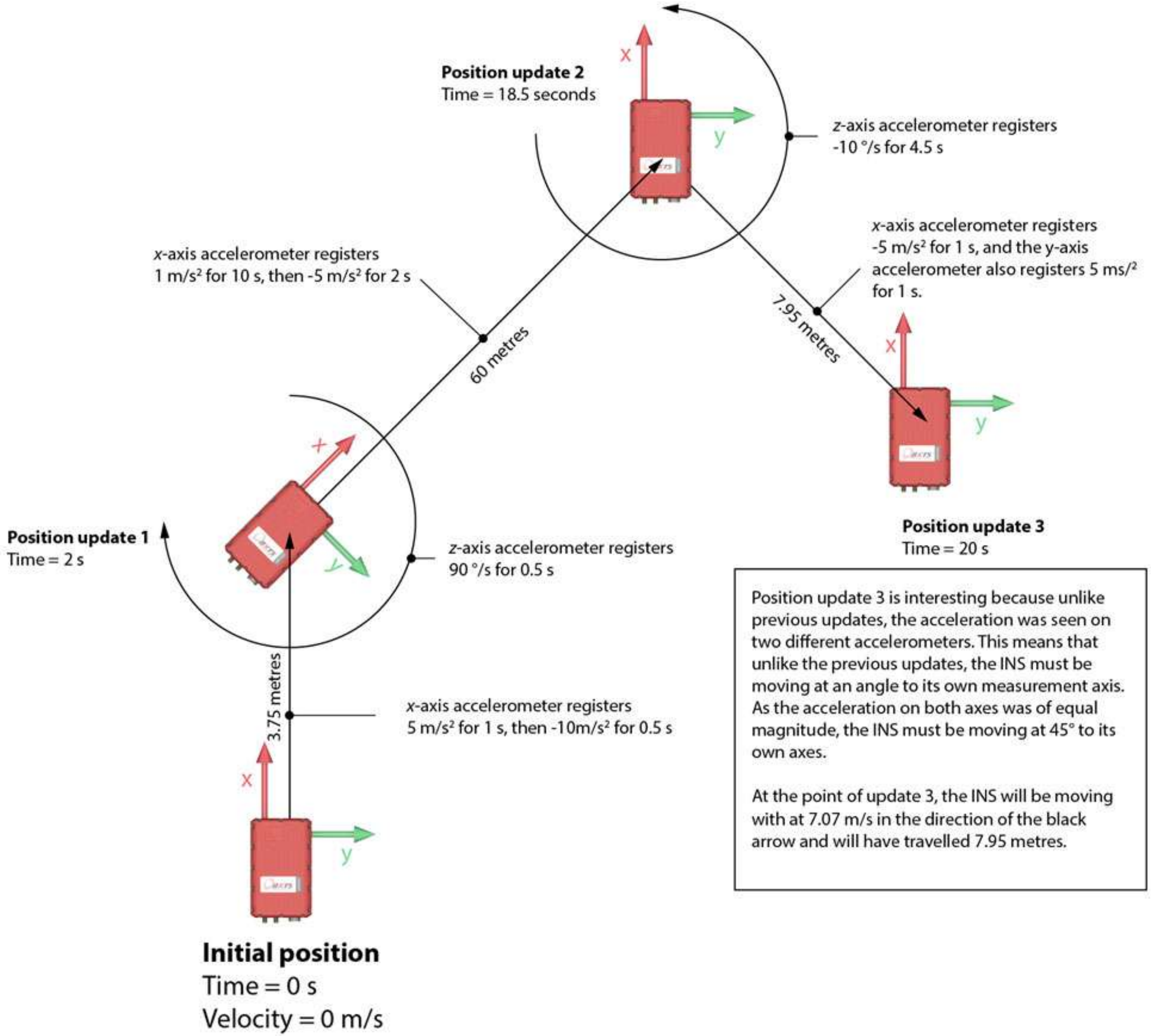
Navigation

Measurements taken from the **three accelerometers** and **three gyros**

The **inertial navigation system** keeps track of where it is in **3D space**.

It does this using a process called **dead reckoning.**

Dead reckoning



Position update 3 is interesting because unlike previous updates, the acceleration was seen on two different accelerometers. This means that unlike the previous updates, the INS must be moving at an angle to its own measurement axis. As the acceleration on both axes was of equal magnitude, the INS must be moving at 45° to its own axes.

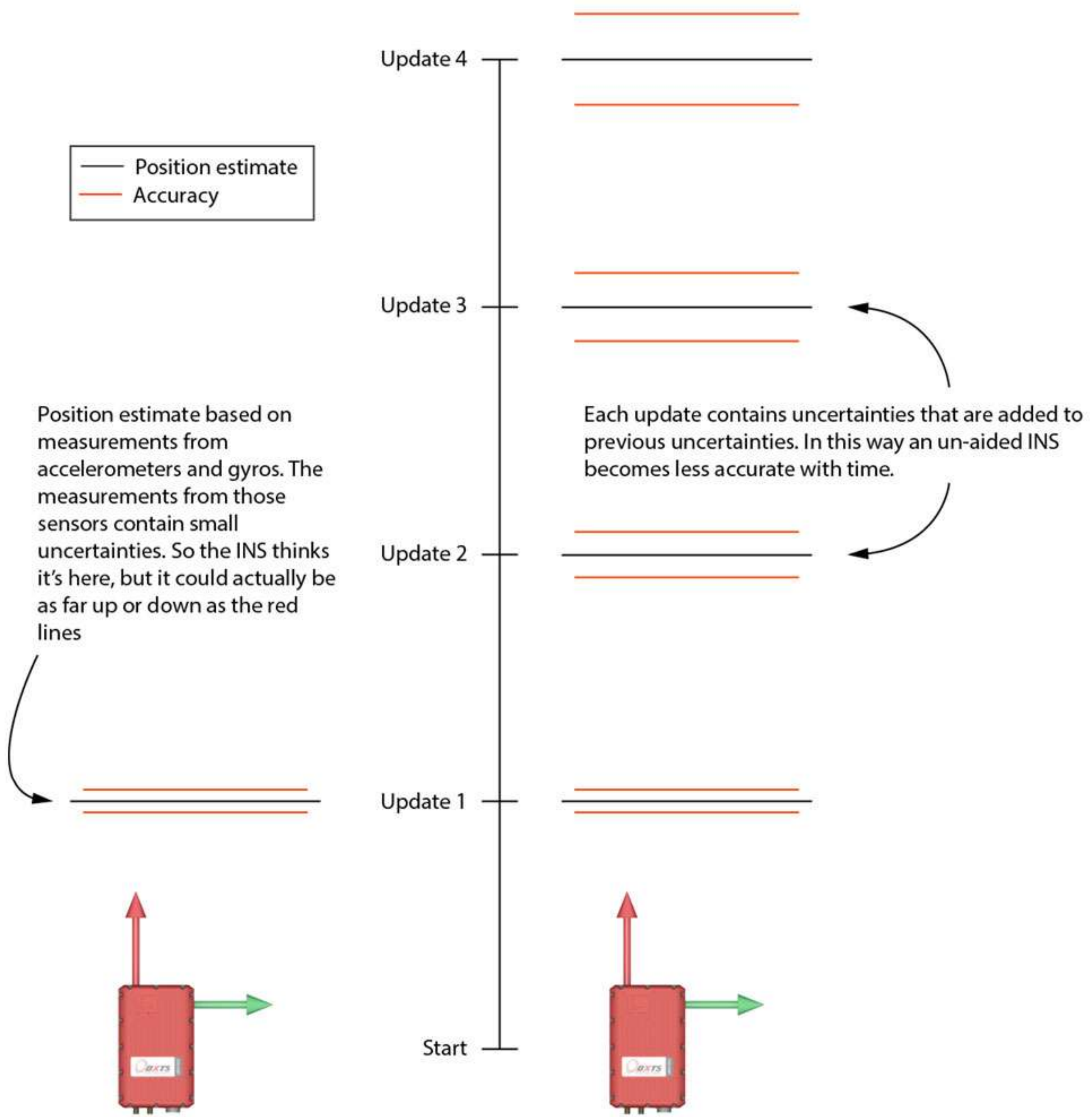
At the point of update 3, the INS will be moving with at 7.07 m/s in the direction of the black arrow and will have travelled 7.95 metres.

Drift

Drift - Achilles heel of basic un-aided inertial navigation systems

Drift is the term used to describe **the accumulation of small errors** in the accelerometer and gyro measurements, which gradually cause the INS position estimate to become more and more inaccurate

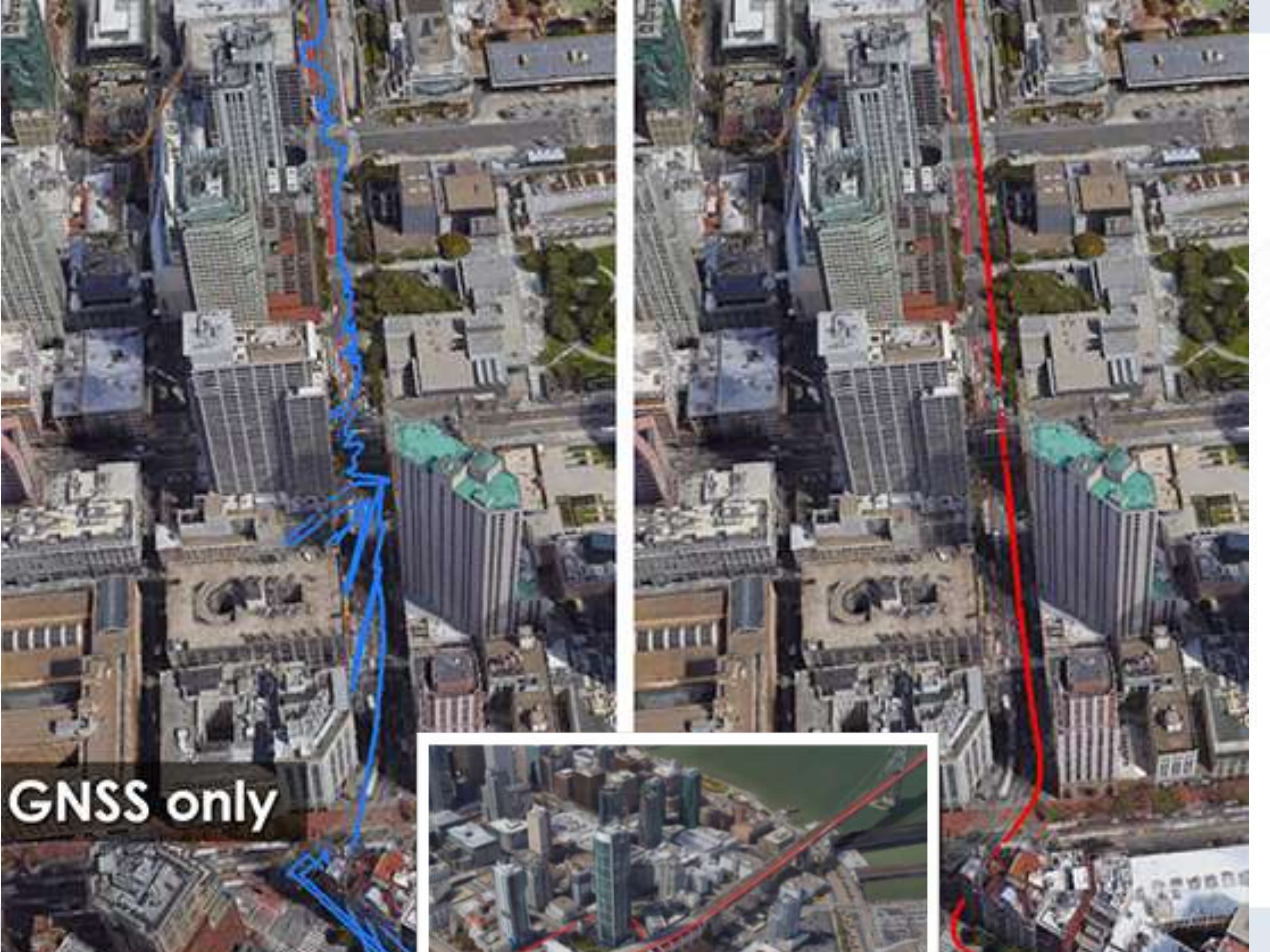
How drift can accumulate in an un-aided INS



GPS+INS

When you combine an **INS with GPS** to create a GPS-aided INS (also written as GPS+INS), you **solve the problem of drift and also solve the problems that affect GPS** too.

Novatel SPAN A1


GNSS only

Autonomous cars

Autonomous cars

Sources:

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- **Kwiatek K.**, Tokarczyk, R., 2018, Photogrammetric 3D measurements Based on Immersive Panoramas [w:] Geomatics and Environmental Engineering, AGH University of Science and Technology Press, vol. 12, no. 4, str. 55-68.
- **Kwiatek K.**, Tokarczyk, R., 2015, Immersive Photogrammetry in 3D Modelling [w:] Geomatics and Environmental Engineering, AGH University of Science and Technology Press, str. 51-62.

Dziękuję za uwagę!

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