

# Inertial navigation systems (INS)



## References

<https://www.oxts.com/what-is-inertial-navigation-guide/>

# Life before GPS

It's hard to imagine life before GPS existed. The truth is, before GPS, if the average person wanted to know where they were, they had to resort to using maps, observations and wildly inaccurate assumptions. And, if the situation got really bad, they asked for directions. However, for individuals and industries with lots of money, plenty of space and a genuine need to know where they were, their salvation frequently came in the form of an INS (inertial navigation system).

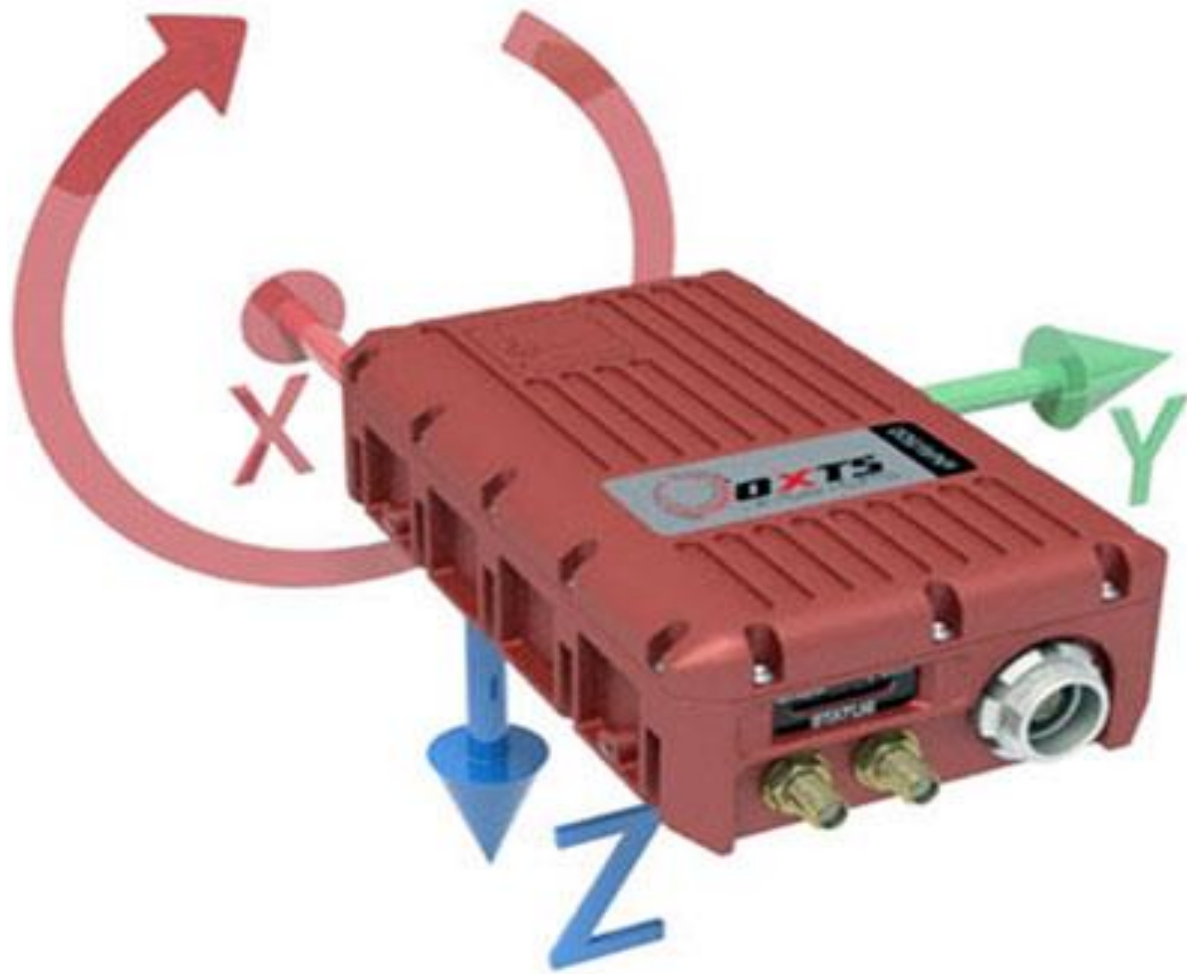
# What is an inertial navigation system?

- Inertial Navigation Systems, unlike other navigation systems, do not depend on external (radio) measurements. Instead an INS keeps track of its position by accurately measuring acceleration (accelerometers) and rotation (gyroscopes). The position measurement of GPS is quite specific. It says ‘you are at this latitude and this longitude’—in other words it gives us an absolute position using a known co-ordinate system. Inertial navigation systems don’t work like that. In their case the measurement they generate is relative to their last known position. So even 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’.
- So why do people use inertial navigation systems at all? If they can’t tell you where you are, how were they able to navigate man to the moon, why don’t submarines crash all the time and how do aeroplanes and missiles find their way? Thankfully the answer to that question is simple. An inertial navigation system works out where it is in relation to where it started—so 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?

- An inertial navigation system comprises two-distinct parts; the first is the IMU (inertial measurement unit). This is the collective name for the accelerometers and gyros that provide acceleration and angular velocity measurements.
- The second part is the navigation computer. The navigation computer takes measurements from the IMU and uses them to calculate the relative position, orientation and velocity of the INS.
- Here are essentially two kinds of navigation computers in use; stabilized platforms and strap down navigators.
- Stabilized platforms use real, spinning mechanical gyroscopes to stabilize a platform that rotates independently to the INS. So, as the inertial navigation system rotates, the stabilized platform inside it does not. In this way the system learns about its orientation and can make use of the measurements from the accelerometers.
- The downsides of this type of system is the high cost and complexity.

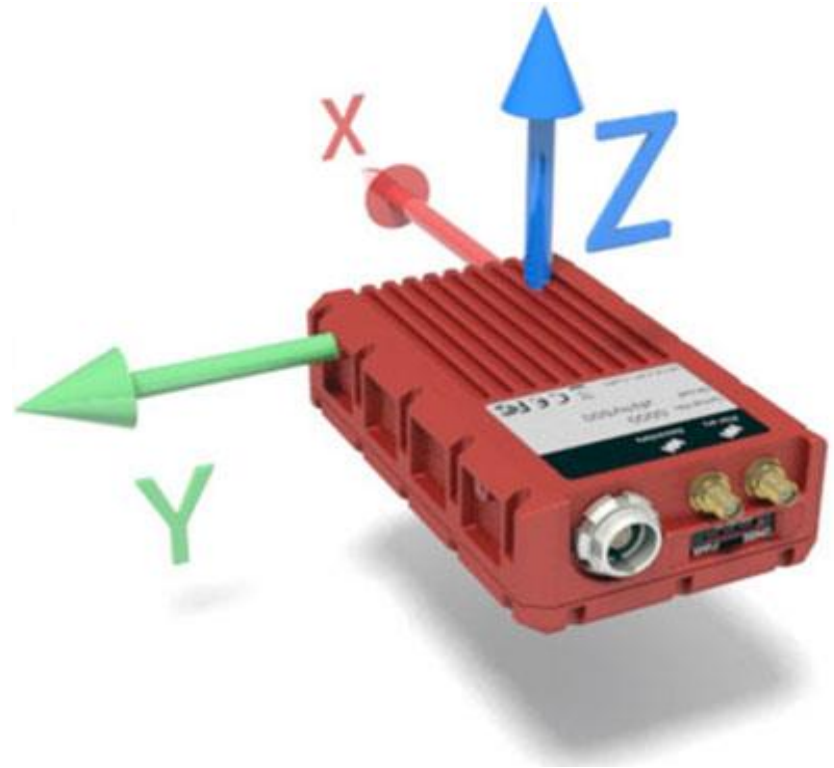
- The sensors inside a strap down navigator do not move independently of the INS. This overcomes many of the problems associated with stabilized platforms and is the main reason why inertial navigation systems are now affordable to a lot more people. Unlike the spinning, mechanical gyros inside a stabilized platform, the gyros used inside a strap down navigator are typically MEMS (Micro Electro Mechanical Systems), which don't appear to have any moving parts.
- So how does an INS 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  $90^\circ$  to the other two



- By taking measurements along the x-, y- and z-axes, the navigation computer can understand how it is moving and rotating. In the IMU frame image, you can clearly see how the measurement xyz-axes are laid out.
- Although each arrow points in one direction, the gyros and accelerometers still measure in both directions along or about each axis. The arrows simply indicate which direction the sensors see as POSITIVE movement. So if the product accelerates down (in the direction of the blue arrow), the Z-axis accelerometer would indicate a positive value; if the product accelerated upwards, the Z-axis accelerometer would show a negative value.



- but what happens if we flip the INS so it's oriented as shown in the image below? Now when the INS accelerates down, the z-axis would register a negative value. This is why frames of reference are important.



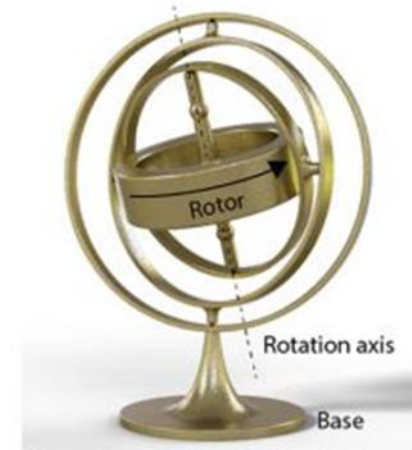
# Accelerometers

- Accelerometers are one of the sensor types used in most inertial navigation systems. They measure acceleration, not velocity.
- Although an 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.
- So having three accelerometers is very useful, especially when they're arranged in a mutually perpendicular way, because they allow the INS to measure acceleration in 3D space and calculate the distance travelled as well as current velocity.
- Accelerometers measure acceleration relative to freefall using the principle described in Newton's second law of motion. That is to say, they measure the relative force acting on a known mass, and use that to calculate the acceleration it must be undergoing.

# Gyros

- Accelerometers are great at measuring straight line motion, but they're no good at rotation—that's where gyros come in. Gyros don't care about linear motion at all, only rotation.
- In a traditional sense, a 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. That type of gyroscope works because once the rotor is spinning, it wants to maintain its axis or rotation.
- Obviously the gyro could be forced to move if you could apply a torque to it—but that's what the gimbal is designed to prevent.

- A gimbal uses a number of concentric rings mounted inside one another that are connected via orthogonally arranged pivots. This design allows the gyro to freely rotate in three-axes.
- 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. In this way, it's possible to maintain a picture of how the external frame is orientated relative to the gyro's axis

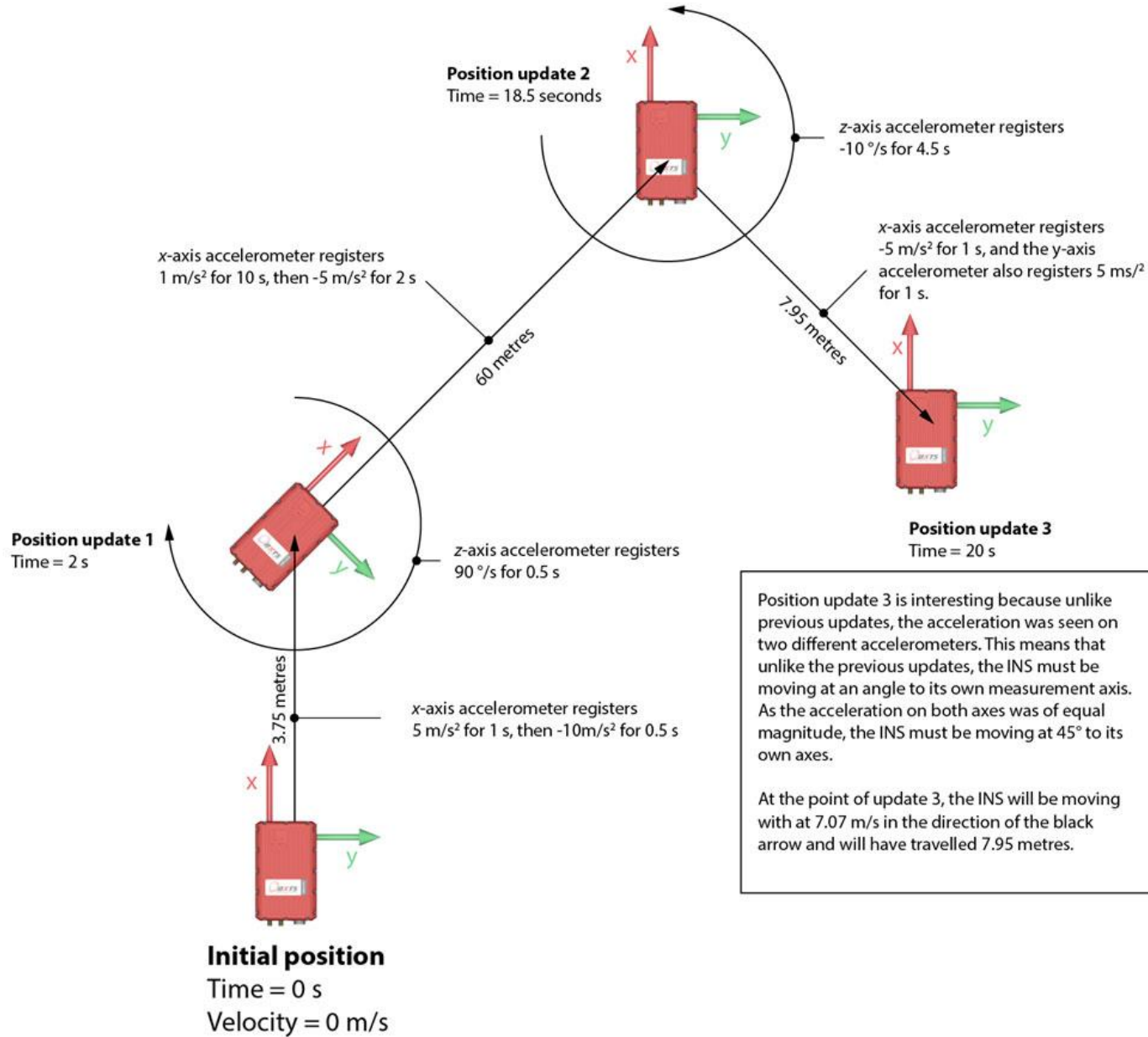


When the rotor is spinning, the base can be moved and rotated in any way and the rotor will try and keep its rotation axis in the same orientation.

# DEAD RECKONING

- Using the measurements taken from the three accelerometers and three gyros, the inertial navigation system keeps track of where it is in three-dimensional space. It does this using a process called dead reckoning. The actual process of dead reckoning is quite easy to understand; you take information from some source (gyros and accelerometers in this case) and turn them into a movement that can be added to your last known position to see where you are now. A simplified 2D example of dead reckoning is shown:

# Dead reckoning



- So at time zero, the INS is stationary (and does not know where it is). It then sees an acceleration of  $5 \text{ m/s}^2$  on the x-axis accelerometer for 1 second, which gives it a velocity of  $5 \text{ m/s}$  (or  $18 \text{ km/h}$ ). It then immediately comes to a complete stop—detecting an acceleration of  $-10 \text{ m/s}^2$  for 0.5 seconds. , the strapdown navigator can easily work out that it has moved 3.75 metres in the direction of the x-axis. As soon as the INS stops at position update 1, the z-axis gyro detects a value of  $90^\circ/\text{s}$  for 0.5 seconds; so it knows that it has just turned  $45^\circ$  in a clockwise direction. Again, as soon as that movement is complete the INS again sees acceleration on the x-axis accelerometer. This time it's  $1 \text{ m/s}^2$  for 10 seconds followed by  $-5 \text{ m/s}^2$  for 2 seconds. Using the same techniques as before, the INS can work out that it has now moved 60 metres further on at a  $45^\circ$  angle from where it was at position update 1. This is what was meant earlier on when we talked about the fact that an INS's position updates were

- relative to the last known position. The last movement is different to previous ones. At position update 2, you can see the INS has rotated so it has the same orientation it has initially. When it then moves towards position 3 however, we can see that the INS is now moving at an angle to its measurement axis (the IMU frame)—it's moving backwards and to the right at a bearing of  $135^\circ$ .
- Because of this movement, acceleration is registered simultaneously on both the x- and y-axis. There is also no negative acceleration causing the INS to stop—so although the measurements on the accelerometers drop to zero after 1 second, the navigation computer knows that the unit still has a velocity. In this case it's moving at  $7.07\text{ m/s}$  (about  $25\text{ km/h}$ ), and position update 3 happens 1.5 seconds after the INS leaves position update 2. In that time the INS has covered 7.95 meters.



# STRENGTHS AND WEAKNESSES

- The main weak point of basic un-aided inertial navigation systems is drift. Un-aided means systems that only use accelerometer and gyro measurements to calculate their position.
- 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.
- Drift in the INS accumulates in the same way. Each time an accelerometer or gyro is read, there is a miniscule error in the reading and because the navigation computer is adding up each measurement to work out how it has moved on from the previous position estimate, the miniscule error grows with time.
- So what about aided ones? 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.

- While raw INS position has mainly been replaced by GPS measurements on oceanic flights, the system is not being phased out. GPS is a sensitive systems and by crosschecking it with INS, errors can be detected in both systems. It is often used as a backup to GPS.
- Integrated GPS / INS systems provide better systems integrity and allow the navigation system to coast through short GPS outages with high accuracies. In addition to that, the (laser) gyroscopes of the INS are often used to provide data to the digital artificial horizon displays in the cockpit and to the auto flight systems. In this case the term Inertial Reference Unit (IRU) is used, which acts as a basis for the INS.
- INS is used primarily as a supplemental source of navigation data and as a fall back when other sources are unavailable.

- Thank you  
for attention