ROBOT LOCALISATION

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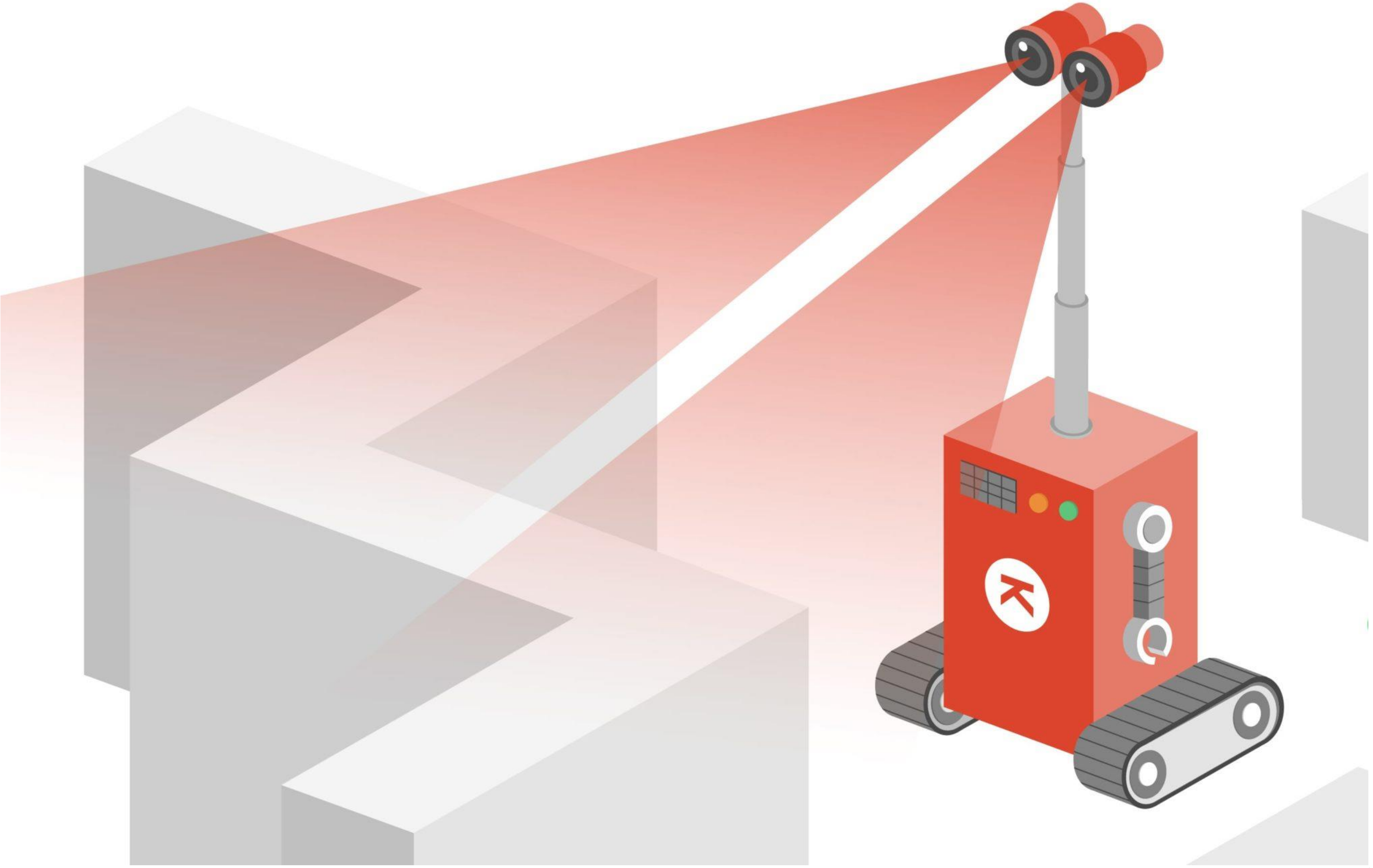
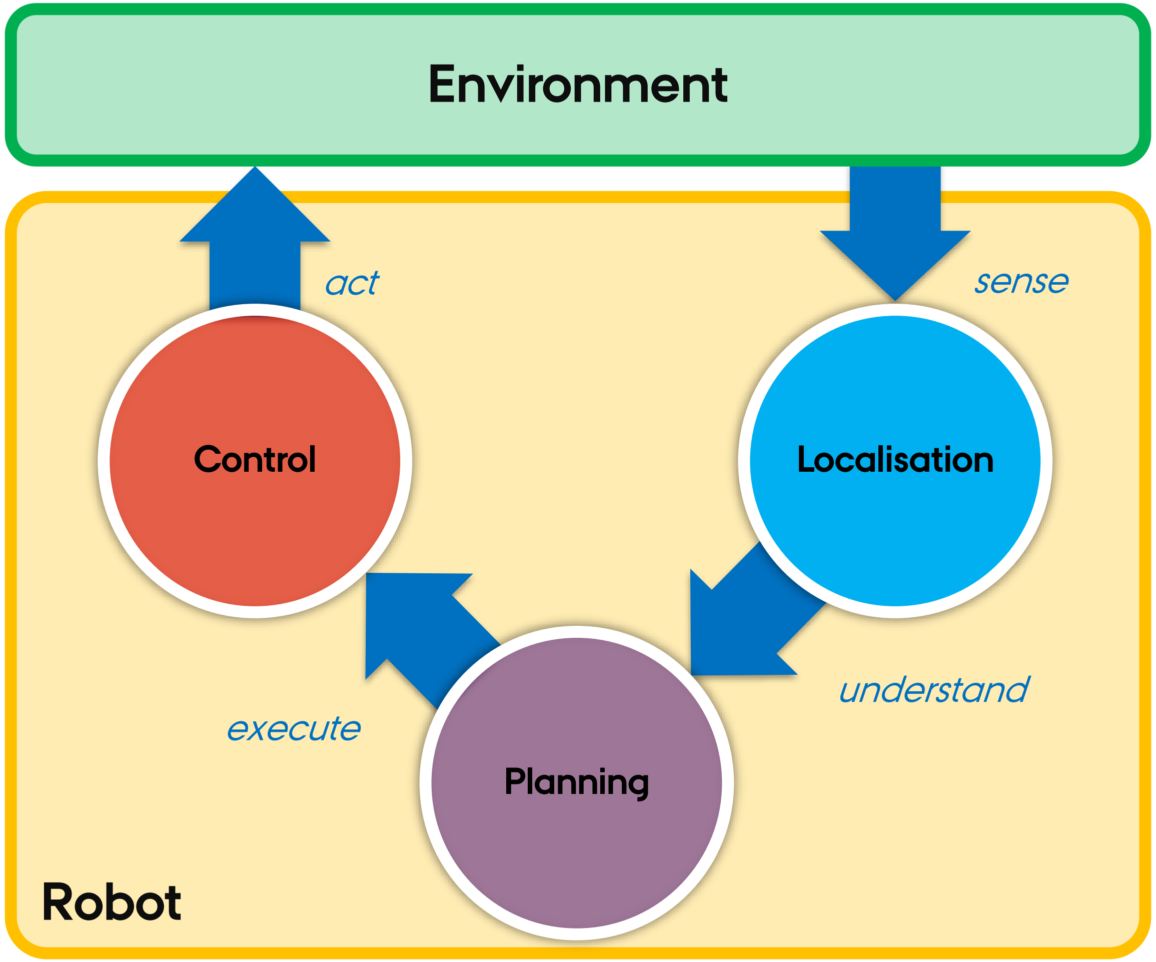
ROBOT LOCALISATION

- **Robot localization** is the process of determining where a mobile robot is located with respect to its environment.

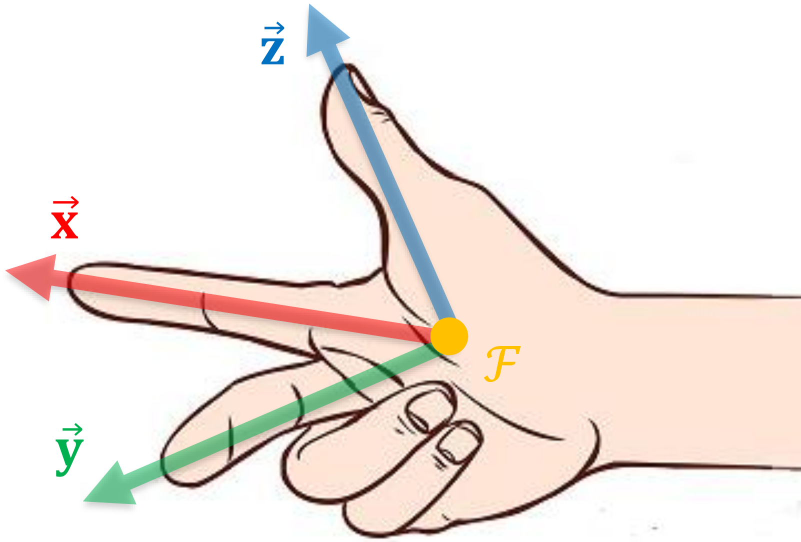


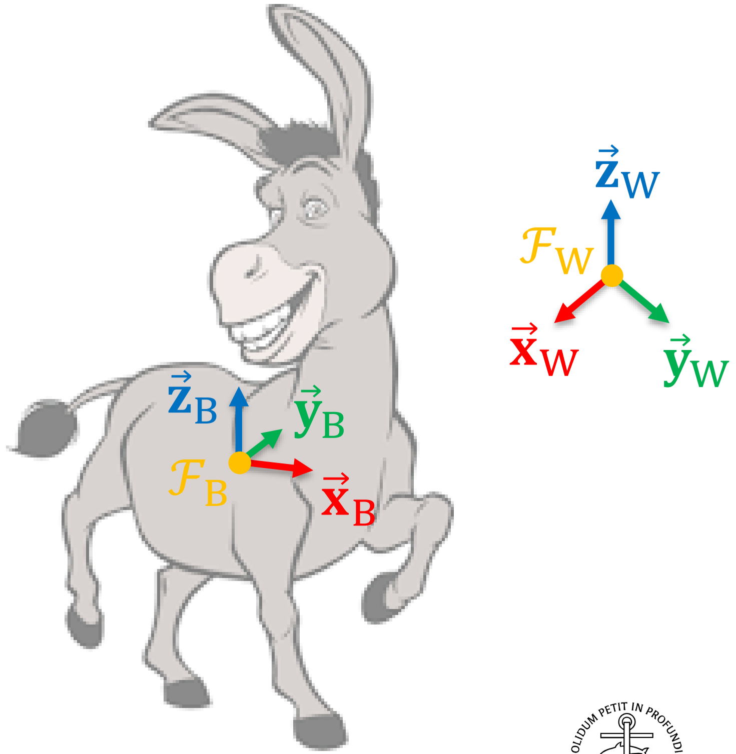
NAVIGATION PARADIGM



REFERENCE FRAME

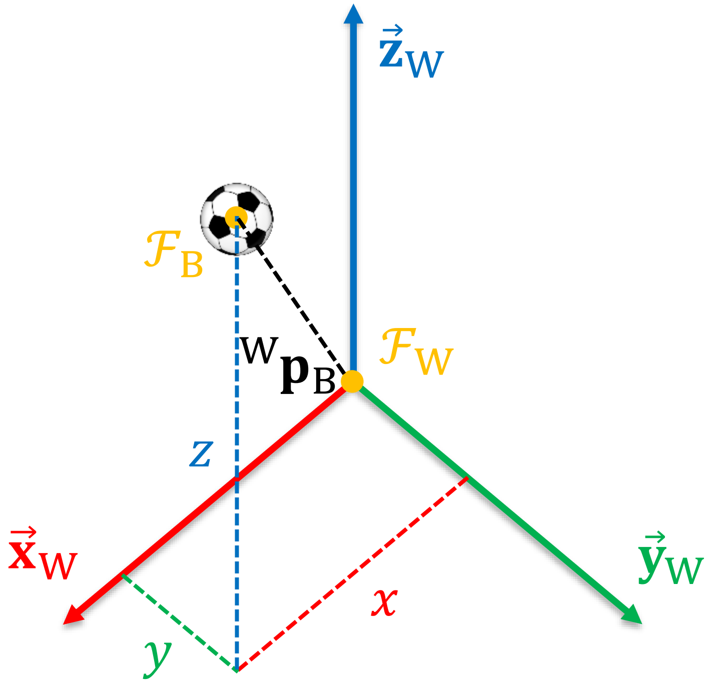
- **Reference frame** is a coordinate system.
- Reference frames are used to describe state of the objects, like *position*, *orientation* and *velocity*, in that frame.
- Each frame $\mathcal{F}$ is defined by its origin and three orthogonal vectors $\vec{\mathbf{x}}$, $\vec{\mathbf{y}}$ and $\vec{\mathbf{z}}$.
- A fixed global frame is called world frame $\mathcal{F}_\mathrm{W}$.
- A moving reference frame is called body frame $\mathcal{F}_\mathrm{B}$.
- We assume that frames follow the right-hand rule.





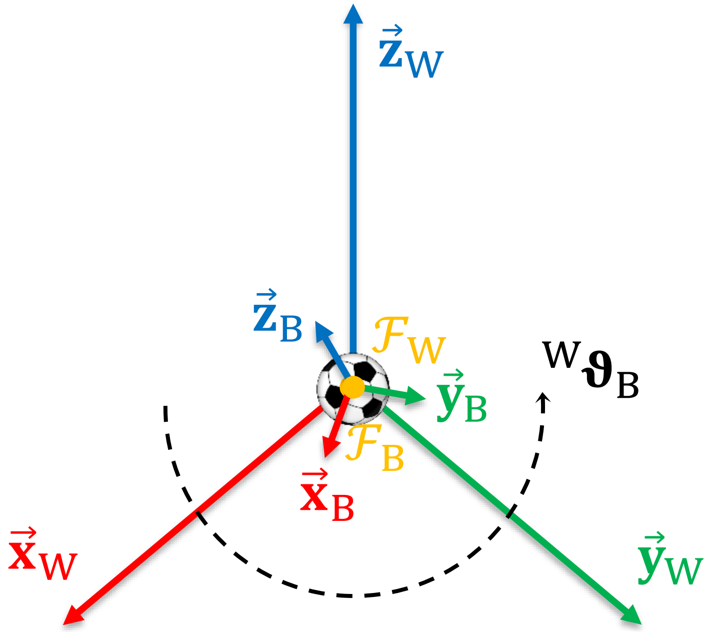
ROBOT POSITION

- **Position** is the translational offset of an object w.r.t a *reference frame*.
- Position is defined by three Cartesian coordinates x, y and z.
- Positions are represented by vectors $\mathbf{p} = \begin{bmatrix} x \\ y \\ z \end{bmatrix} \in \mathbb{R}^3$.
- Position of a frame $\mathcal{F}_\mathrm{B}$ with respect to a frame $\mathcal{F}_\mathrm{A}$ is indicated by ${}^\mathrm{A}\mathbf{p}_\mathrm{B}$.
- We assume that positions are expressed in the world reference frame.
- Position is measured in *meters* [m].



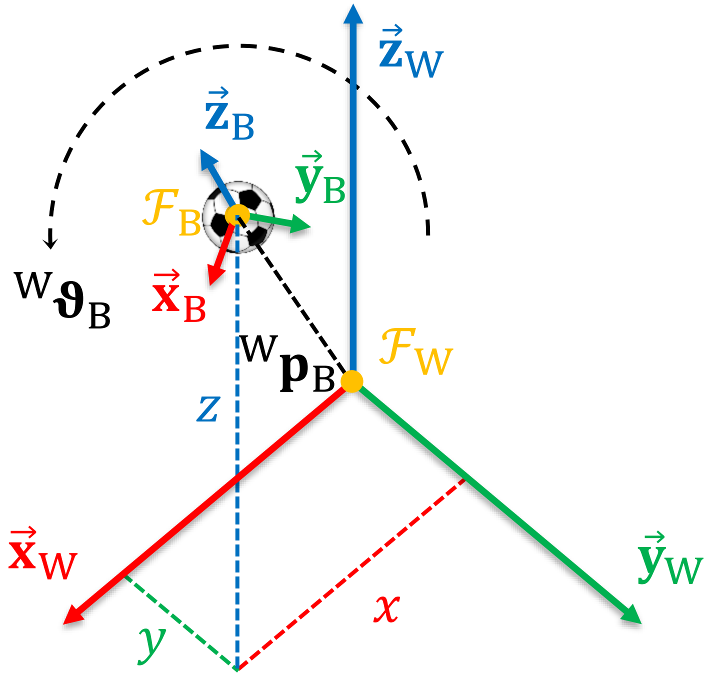
ROBOT ORIENTATION

- **Orientation** is the directional displacement of an object w.r.t. a *reference frame*.
- Orientation can be parametrized by three Euler's angles: roll ϕ, pitch θ and yaw ψ.
- Orientation of a frame $\mathcal{F}_\mathrm{B}$ with respect to a frame $\mathcal{F}_\mathrm{A}$ is indicated by ${}^\mathrm{A}\boldsymbol{\vartheta}_\mathrm{B}$.
- Orientation can be described by a rotation matrix ${}^\mathrm{A}\mathbf{R}_\mathrm{B}$.
- We assume that orientations are expressed in the <u>world</u> reference frame.
- Orientation is measured in *radians* [rad].



ROBOT POSE

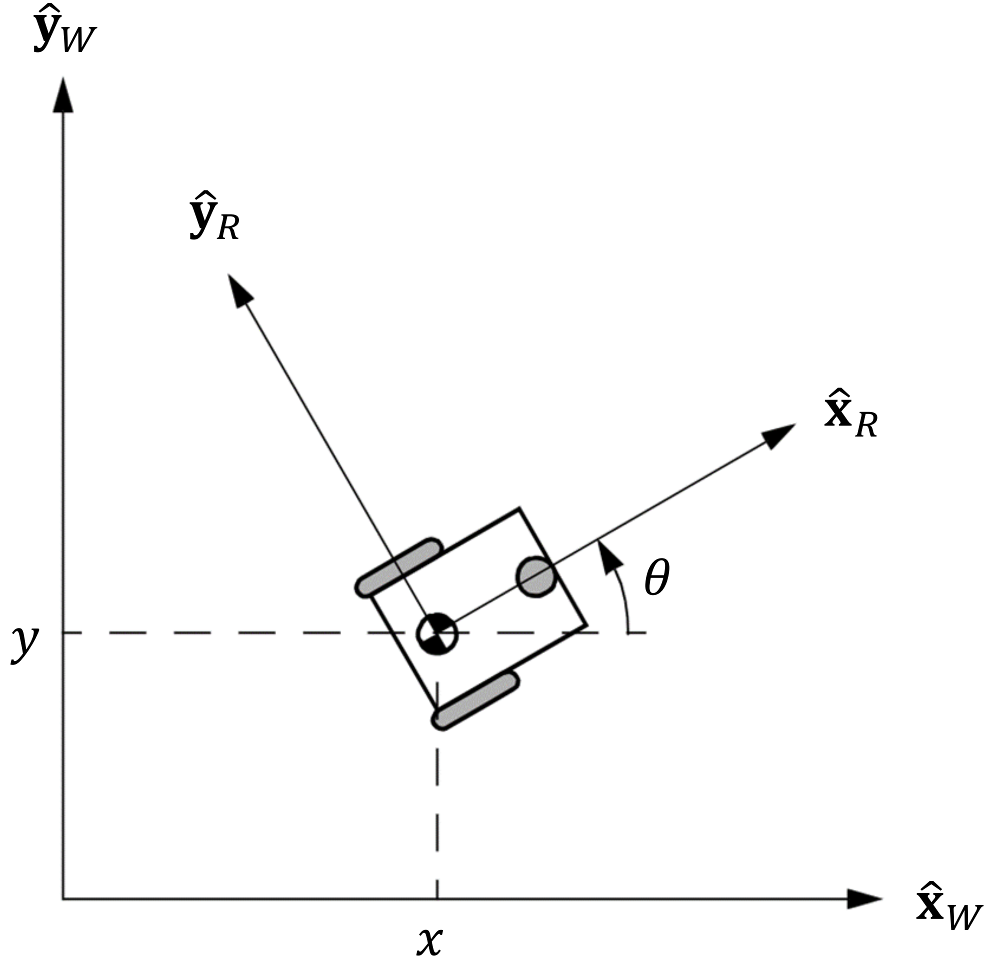
- **Pose** is the combination of *position* and *orientation*.
- Pose fully describes the configuration of a body in the space.
- Pose can be interpreted as a homogeneous transformation matrix ${}^{\mathrm{A}}\mathbf{T}_{\mathrm{B}} = \begin{bmatrix} {}^{\mathrm{A}}\mathbf{R}_{\mathrm{B}} & {}^{\mathrm{A}}\mathbf{p}_{\mathrm{B}} \\ \mathbf{0} & 1 \end{bmatrix} \in \mathbb{R}^{4\times 4}$.
- To apply a transformation ${}^{\mathrm{A}}\mathbf{T}_{\mathrm{B}}$ to a point ${}^{\mathrm{A}}\mathbf{p}$: ${}^{\mathrm{B}}\mathbf{p} = {}^{\mathrm{A}}\mathbf{T}_{\mathrm{B}}\,{}^{\mathrm{A}}\mathbf{p}$.



ROBOT STATE

- State of a wheeled robot is

$$\begin{bmatrix} x \\ y \\ \theta \end{bmatrix}$$



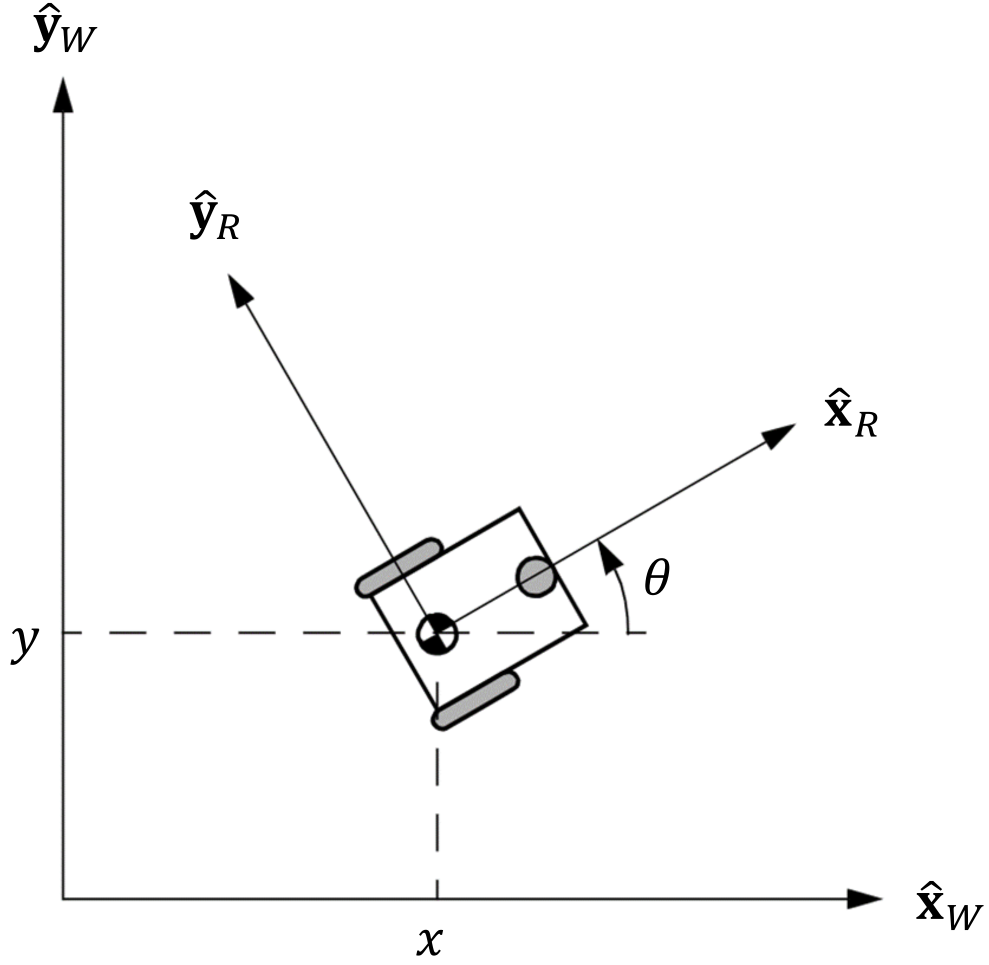
ROBOT KINEMATICS

- **Kinematics** is the description of the rules of bodies motion.
- Kinematics of a wheeled robot is

$$\begin{cases} \dot{x} = v\cos\theta \\ \dot{y} = v\sin\theta \\ \dot{\theta} = \omega \end{cases}$$

- With discrete time $\Delta t[k] = t[k] - t[k-1]$:

$$\begin{cases} x[k+1] = x[k] + v[k]\cdot\cos\theta[k]\cdot\Delta t[k] \\ y[k+1] = y[k] + v[k]\cdot\sin\theta[k]\cdot\Delta t[k] \\ \theta[k+1] = \theta[k] + \omega[k]\cdot\Delta t[k] \end{cases}$$

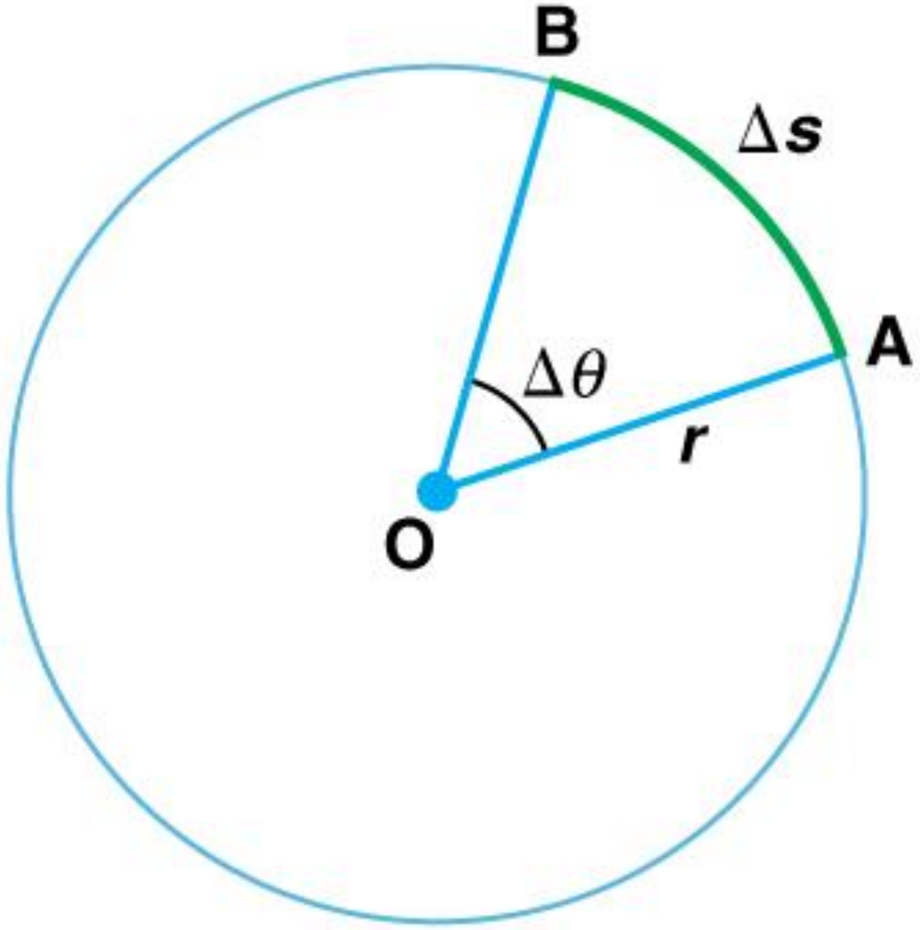


WHEEL ENCODER

- **Wheel encoder** is an electro-mechanical device that measures the angular position of the wheel.

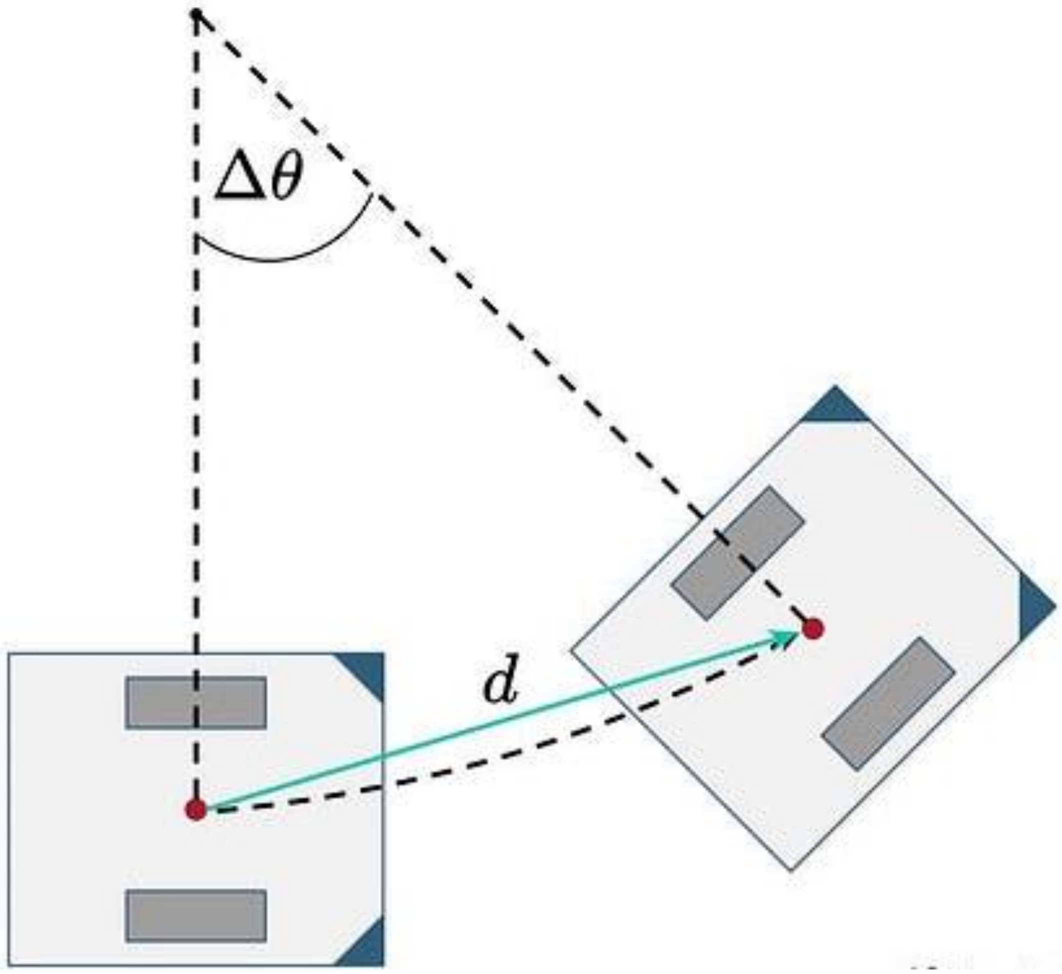
- Wheel encoders allows to estimate the travelled distance:

$$\Delta s = r \cdot \Delta\theta$$



WHEEL ODOMETRY

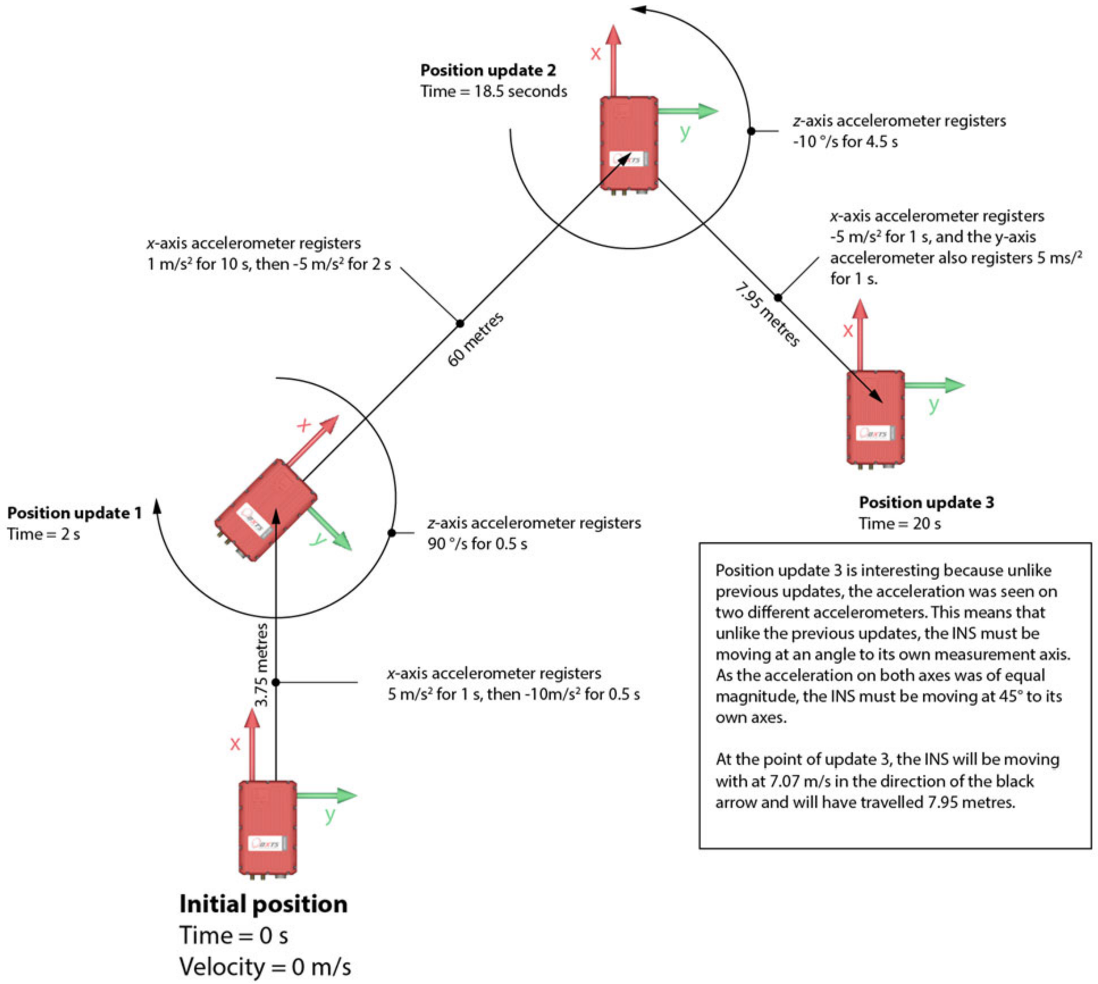
- **Wheel odometry** is the use of data from wheel encoders to estimate change in *position*.
- Wheel odometry is used for wheeled robots to estimate their *position* relative to a starting location.
- Wheel odometry is sensitive to errors due to the integration of velocity measurements over time.
- Wheel odometry is sensitive to wheel slip.
- Wheel odometry cannot solve the kidnapped robot problem.



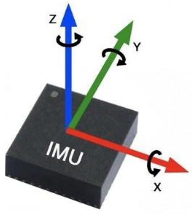
DEAD RECKONING

- **Dead reckoning** is the estimation of a robot's pose based on its estimated *acceleration*, *direction* and *time* of travel with respect to a previous estimate.

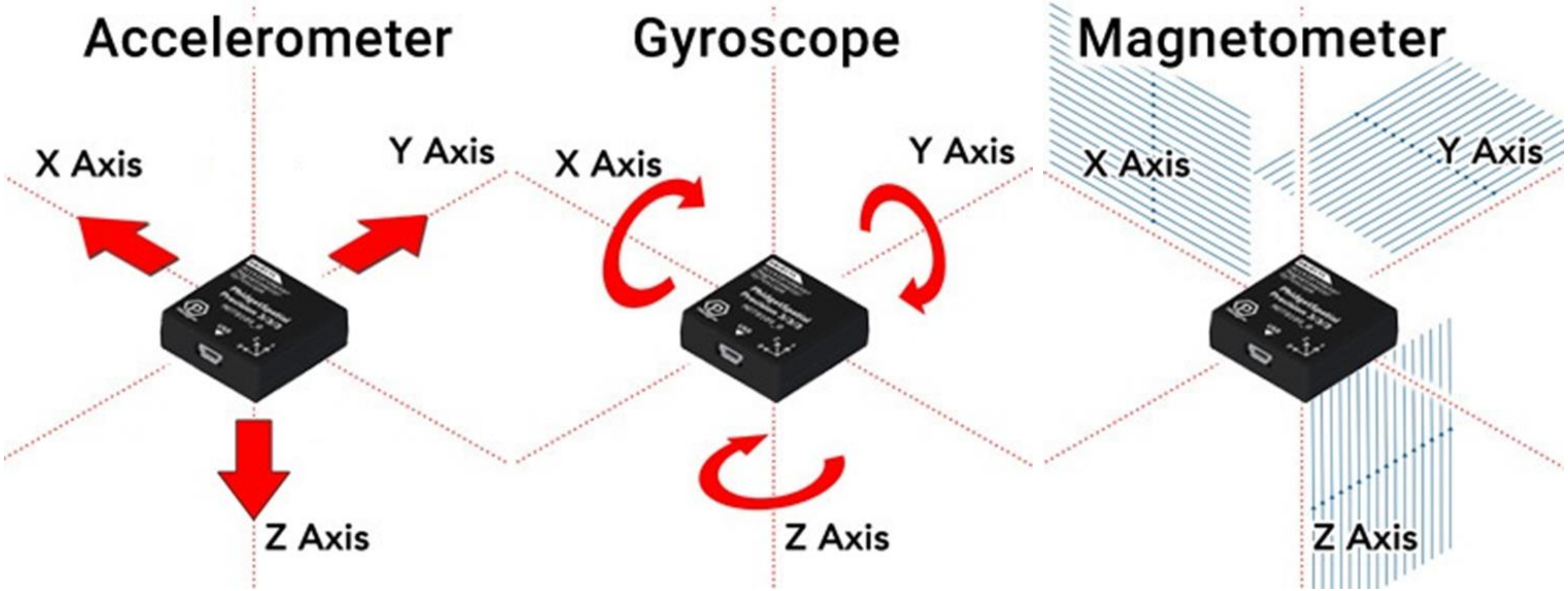
- Dead reckoning can be implemented by using only inertial (IMU) data: *acceleration* and *orientation*.



INERTIAL MEASUREMENT UNIT



- **Inertial measurement unit** (IMU) combines <u>3 accelerometers</u> for *linear acceleration*, <u>3 gyroscopes</u> for *angular velocity* and <u>3 magnetometers</u> for *orientation*.



INERTIAL ODOMETRY

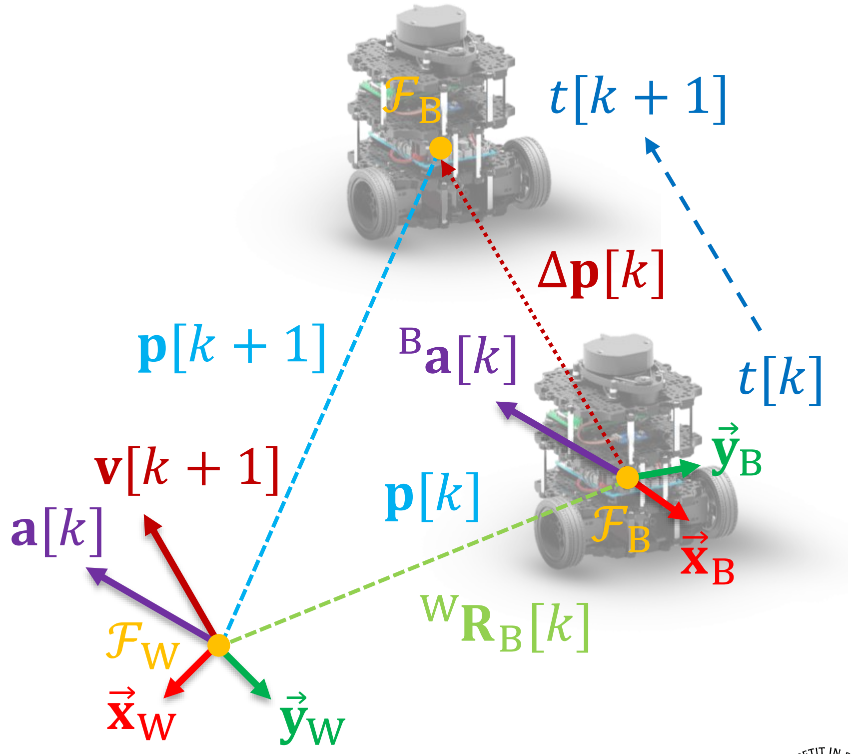
- **Inertial odometry** is the process of determining the position and orientation of a robot from robot's inertial information.

- *Position* calculation:

$$\mathbf{a}[k] = {}^{\mathrm{B}}\mathbf{R}_{\mathrm{W}}[k] \cdot {}^{\mathrm{B}}\mathbf{a}[k]$$

$$\mathbf{v}[k+1] = \mathbf{v}[k] + \mathbf{a}[k] \cdot \Delta t[k]$$

$$\mathbf{p}[k+1] = \mathbf{p}[k] + \underbrace{\mathbf{v}[k] \cdot \Delta t[k] + \frac{1}{2}\mathbf{a}[k] \cdot \Delta t[k]^2}_{\Delta \mathbf{p}[k]}$$



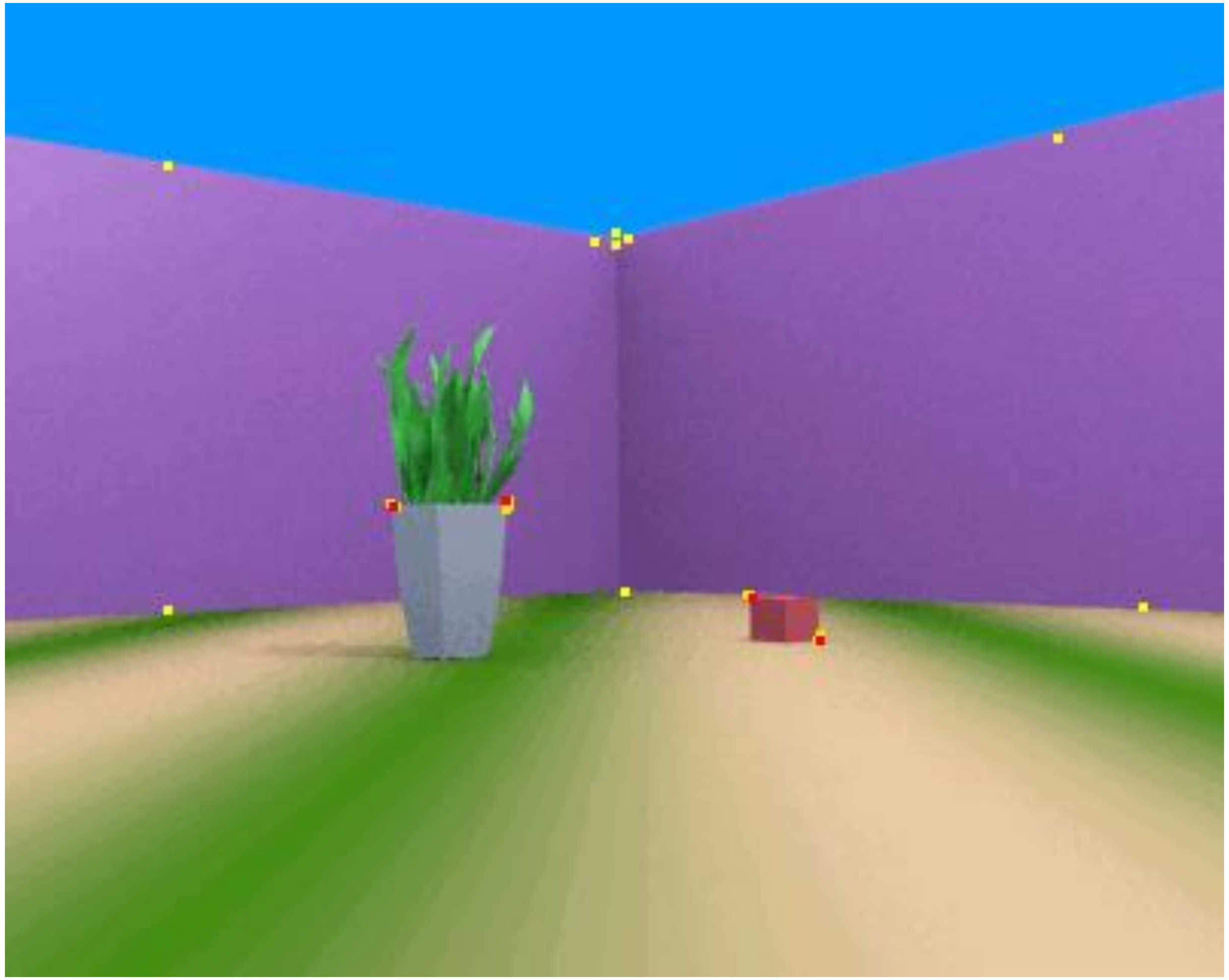
- *Orientation* can be obtained directly form the <u>magnetometer</u>.

VISUAL ODOMETRY

- **Visual odometry** is the process of determining the position and orientation of a robot by analyzing the associated camera images.

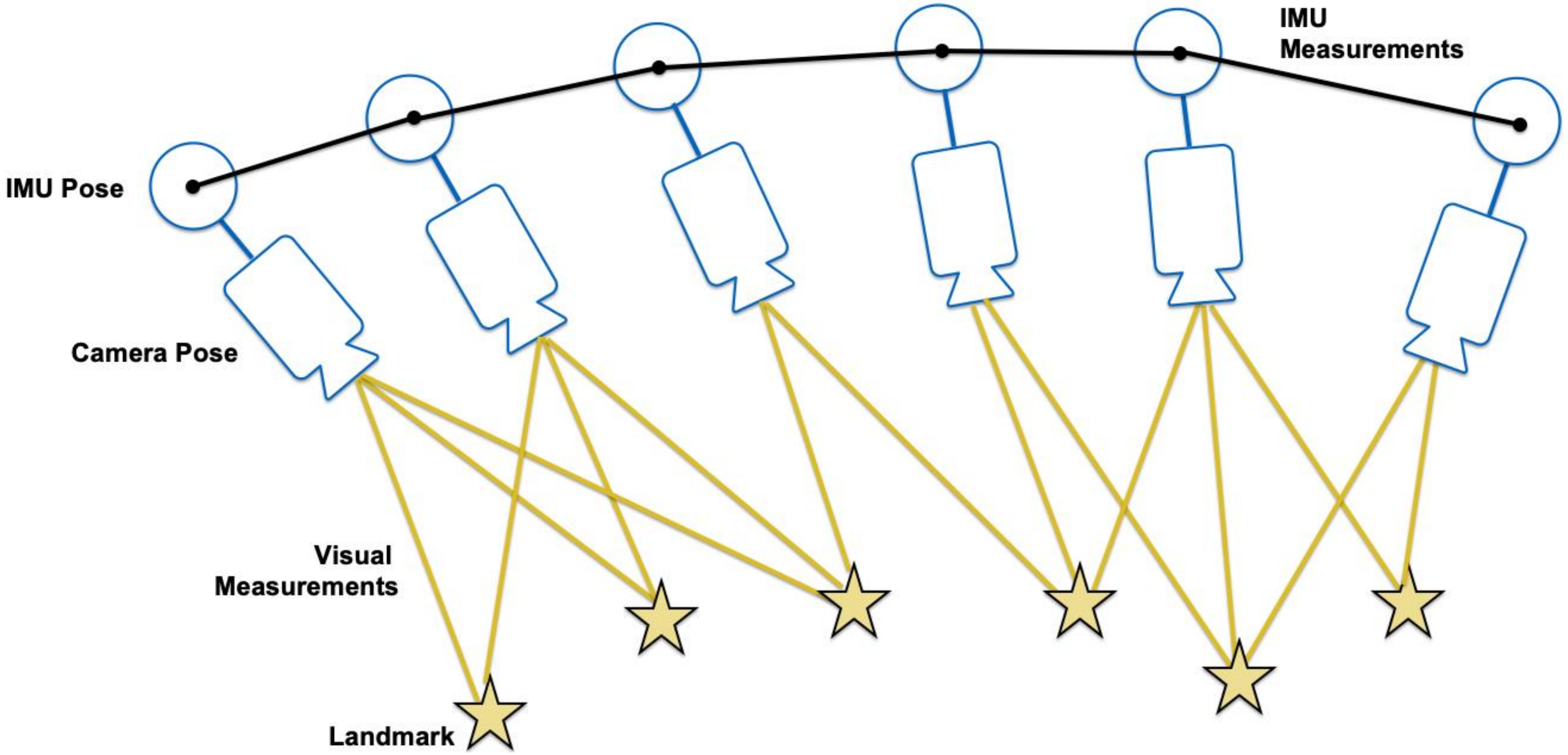
- Visual odometry extracts the image feature points and tracks them in the image sequence.

- Depending on the camera setup, visual odometry can be *monocular* (single camera) or *stereo* (two cameras in stereo setup).



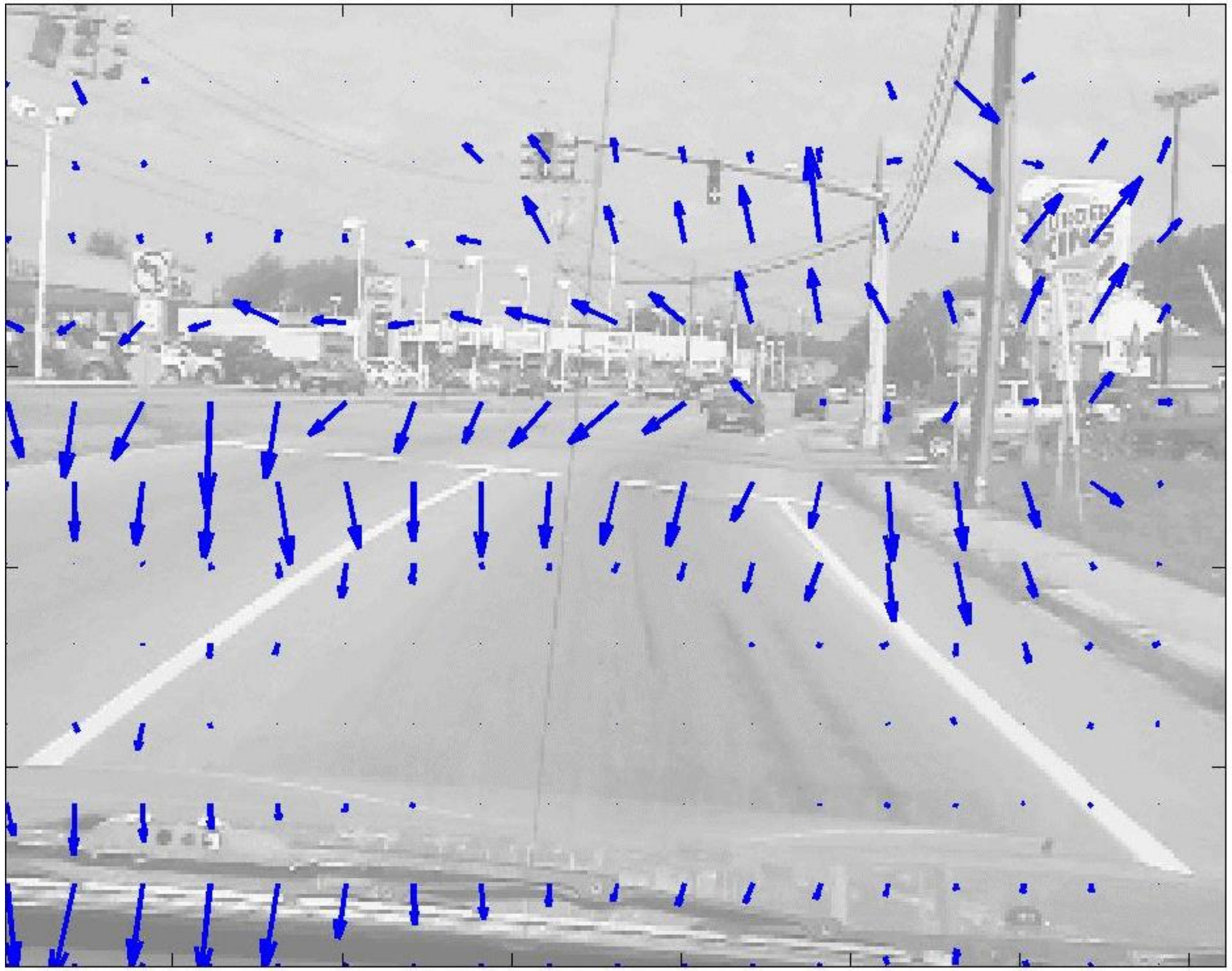
VISUAL-INERTIAL ODOMETRY

- **Visual-inertial odometry** (VIO) is the process of estimating the pose of a robot by using a camera and an IMU.
- VIO uses images from a camera to estimate translation and data from IMU to estimate rotation.



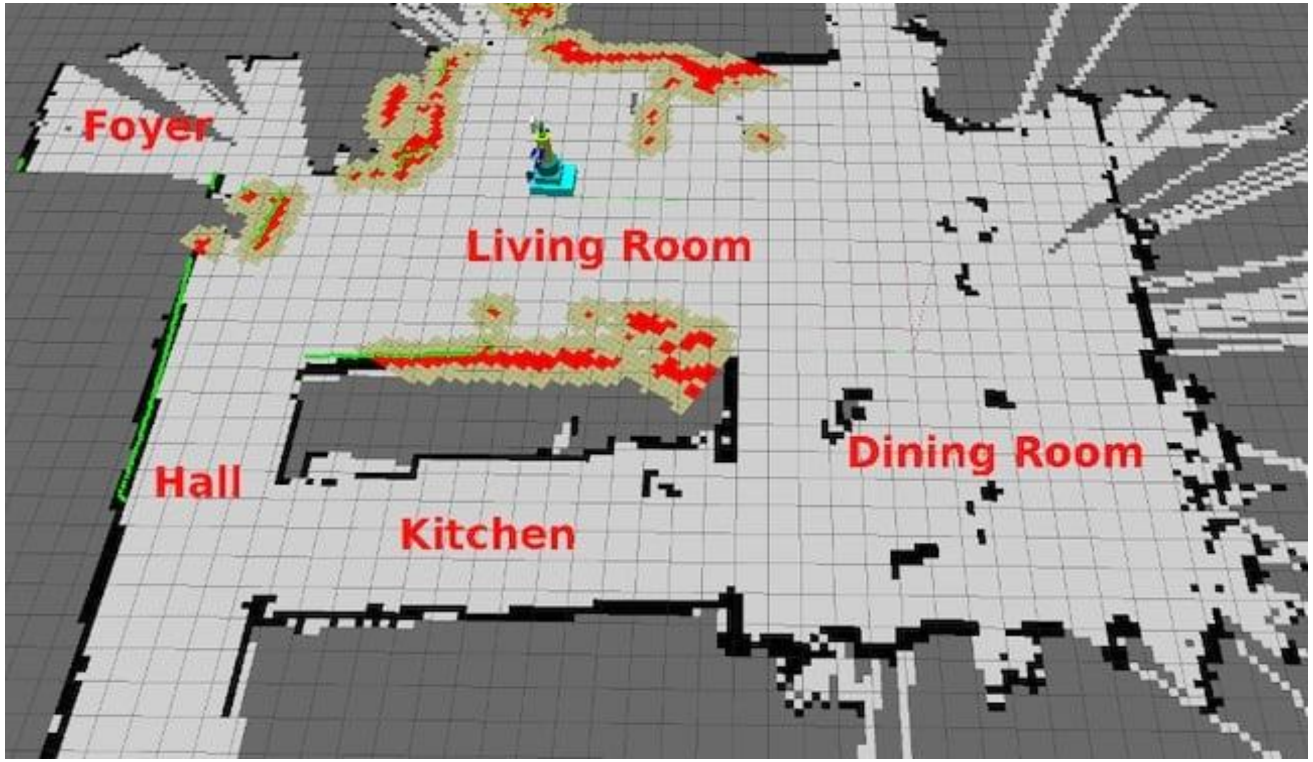
OPTICAL FLOW

- **Optical flow** is the pattern of apparent motion of objects in a visual scene caused by the relative motion between the camera and the scene.
- Optical flow can also be defined as the distribution of apparent velocities of movement of pixels in an image.
- Optical flow allows to estimate the linear (translational) *velocity* of the robot.



ROBOTIC MAPPING

- **Robotic mapping** is a problem of constructing a map by an autonomous robot.
- Mapping can be performed by moving lidar or cameras in the environment.

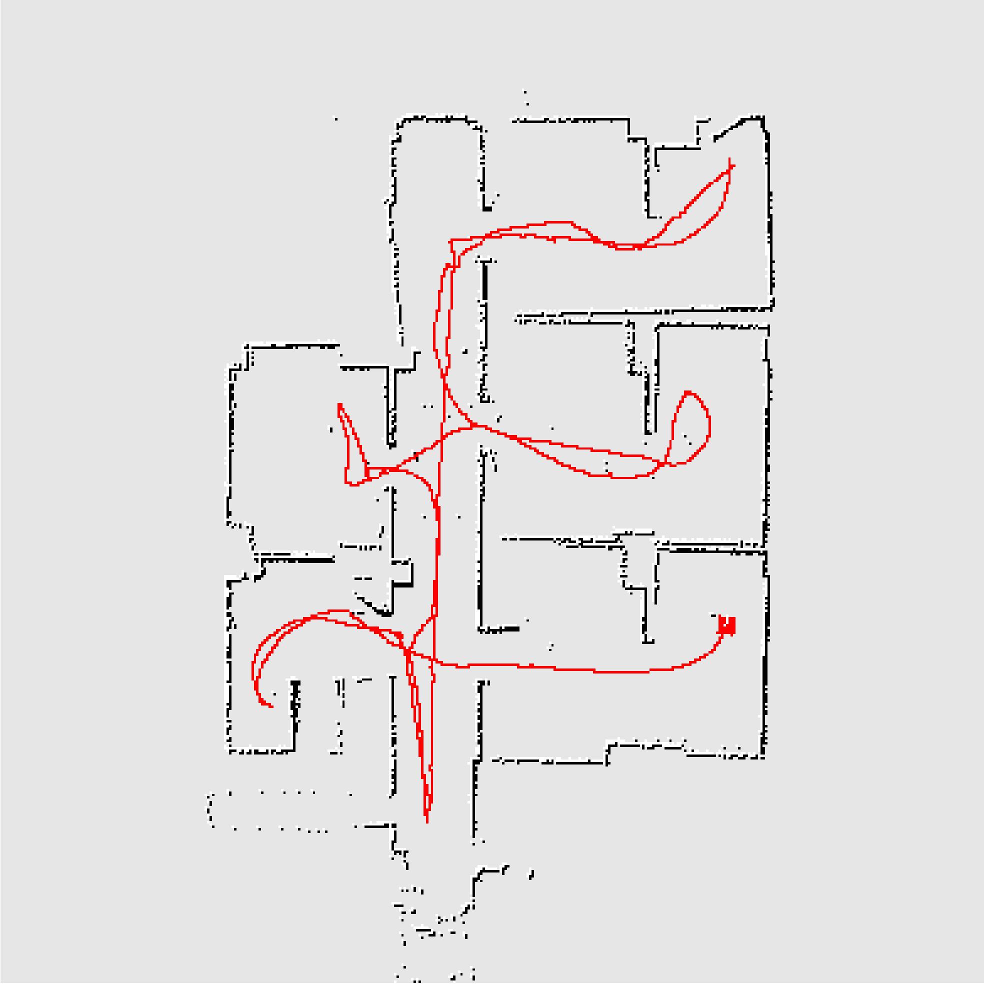


SIMULTANEOUS LOCALIZATION AND MAPPING

- **Simultaneous localization and mapping** (SLAM) is an approach for constructing a map of an unknown environment while simultaneously keeping track of robot's location.

- Popular approximate solution methods include the *particle filter*, *extended Kalman filter* and *covariance intersection*.

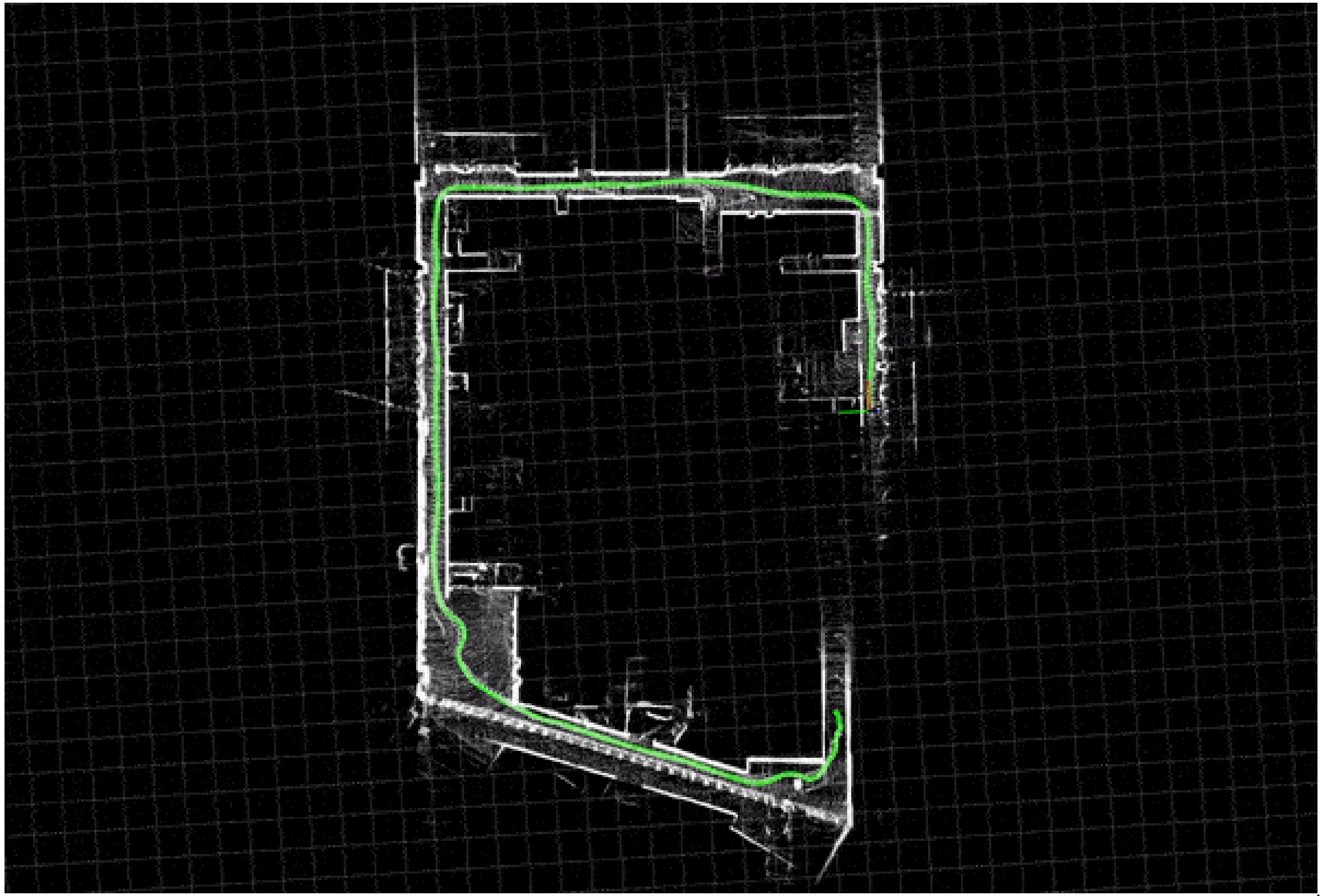
- SLAM algorithms are based on concepts in computational geometry (and computer vision).



LOOP CLOSURE

- **Loop closure** is a sub algorithm of SLAM for identifying previously visited locations to correct the accumulated errors in the robot's pose estimation.

- Loop closure is an iterative optimization algorithm.

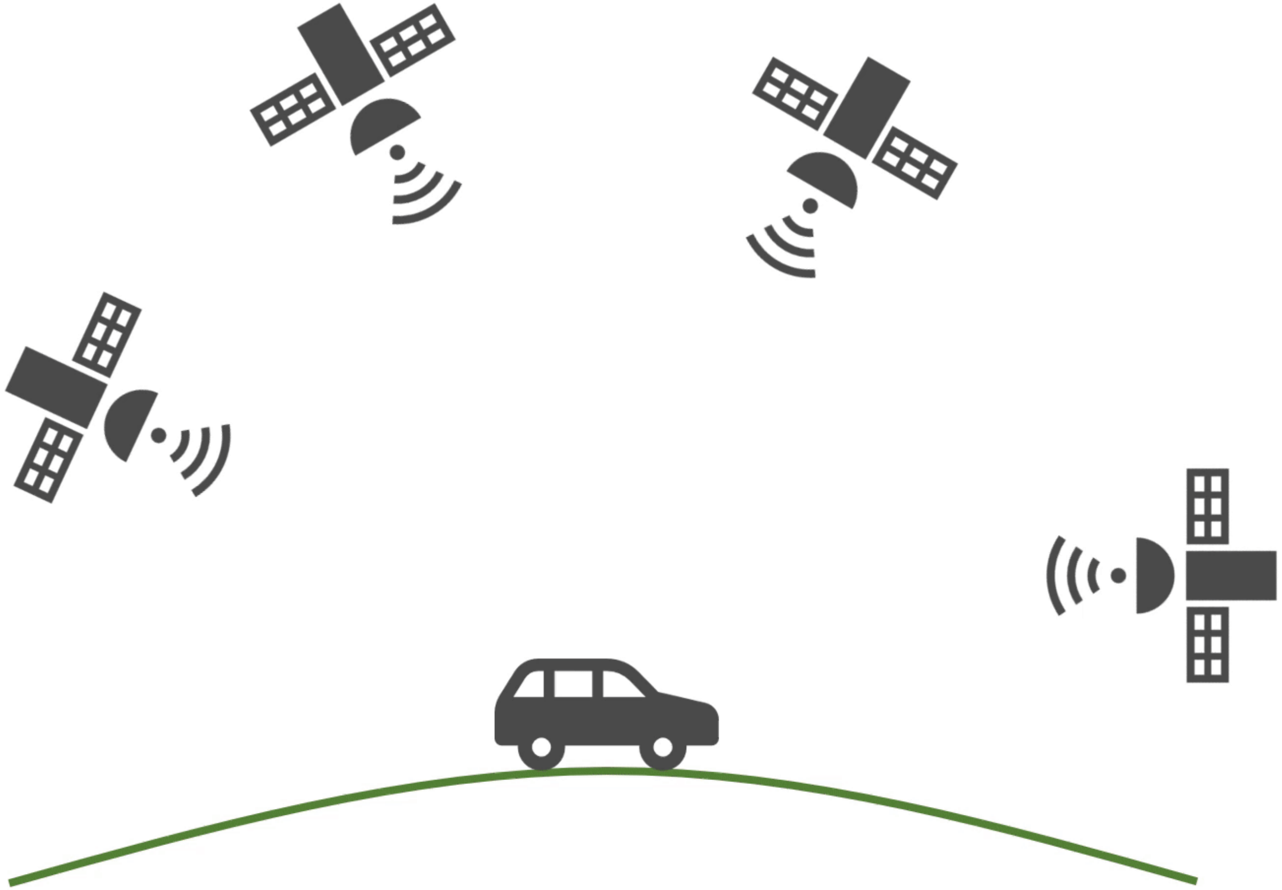


GLOBAL POSITIONING SYSTEM

- **Global positioning system (GPS)** provides geolocation and time information to a GPS receiver anywhere on the Earth where there is an unobstructed line of sight

- GPS provides localization in the global reference frame.

- GPS has no coverage indoors.



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