Motion Tracking using IMU sensors

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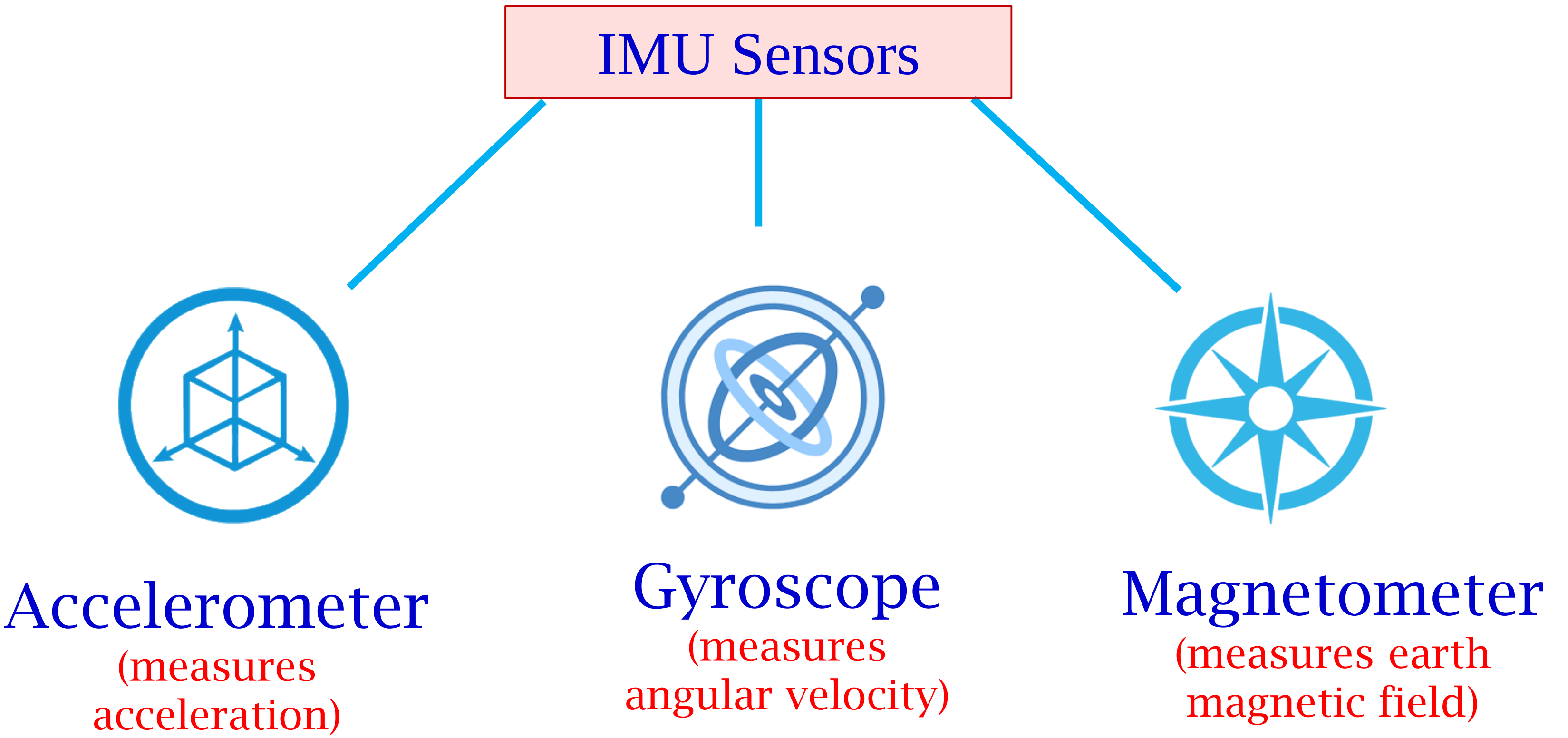
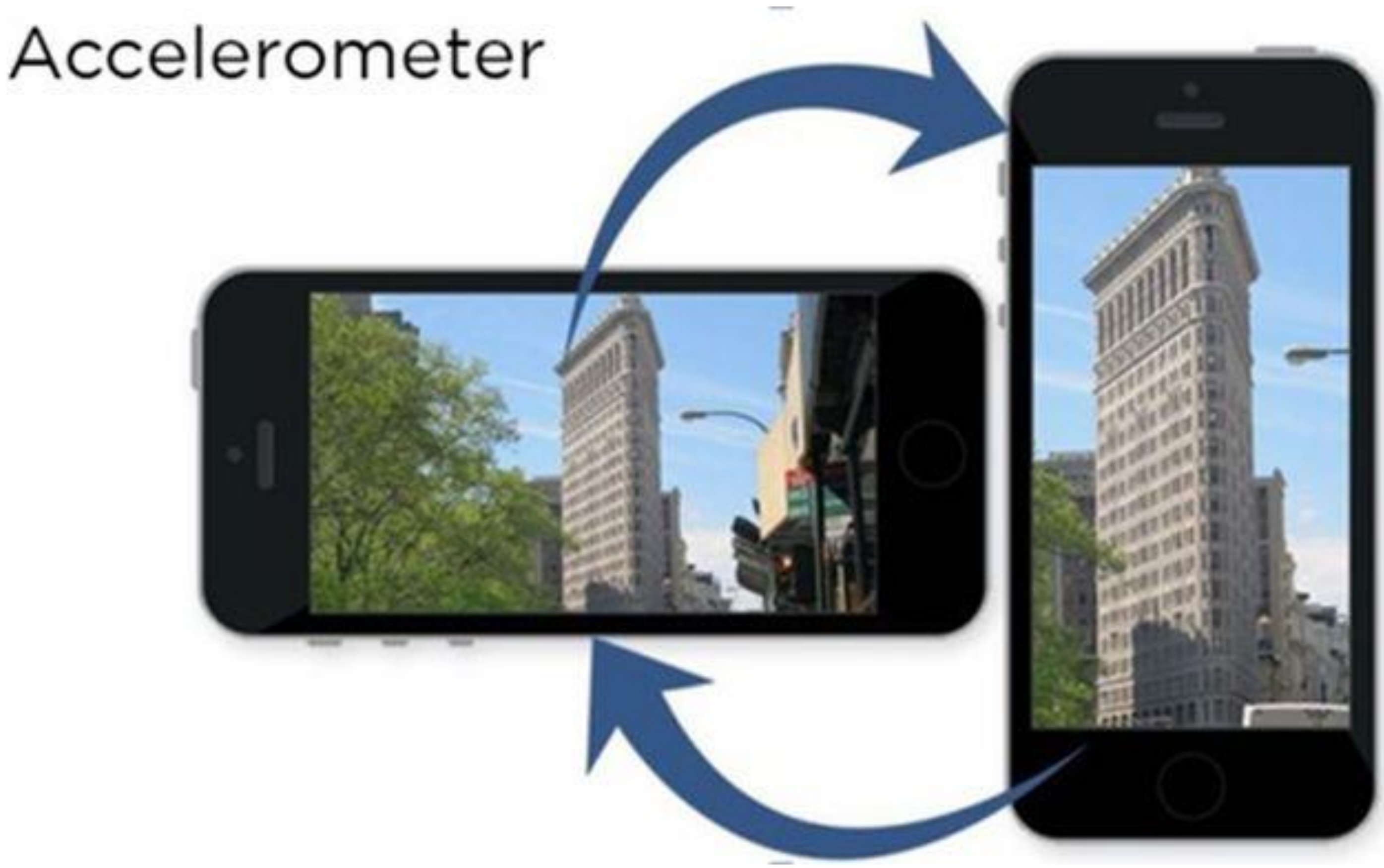
IMU Sensors



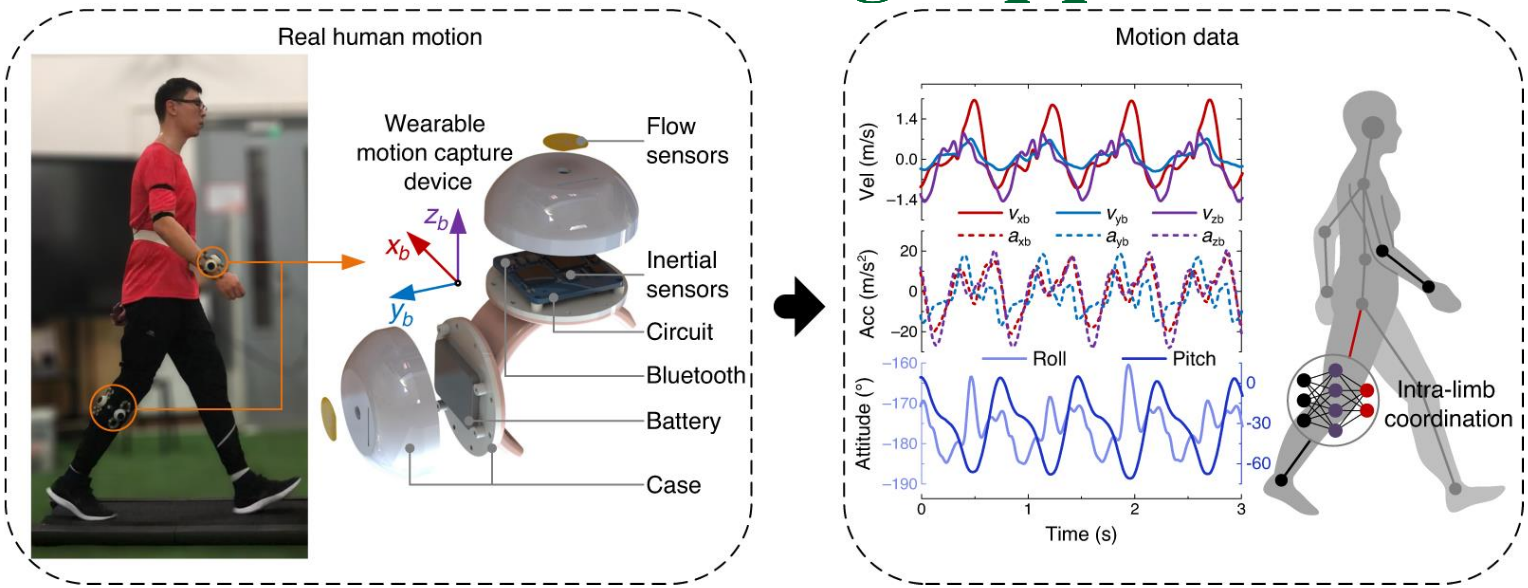
Install **Physics Toolbox Sensor Suite** in your smartphone

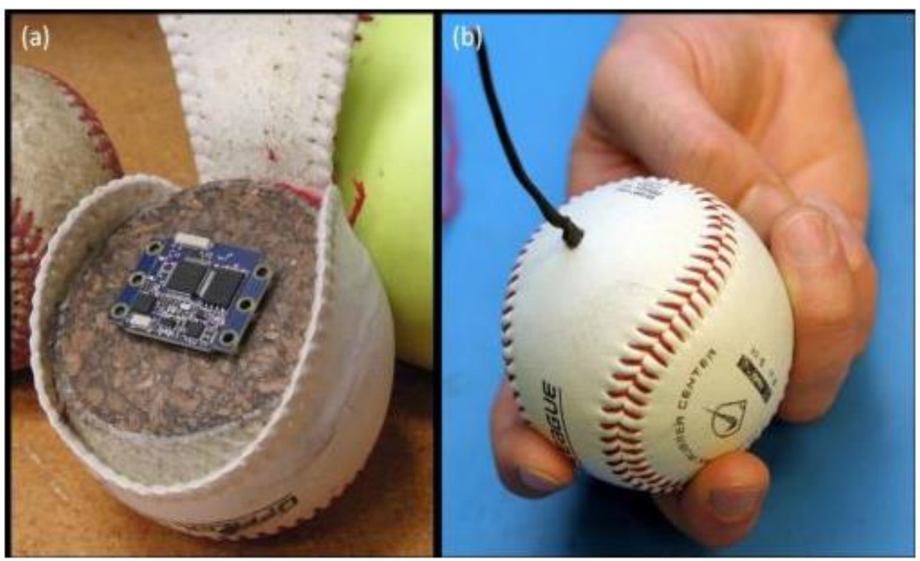
IMU Sensors

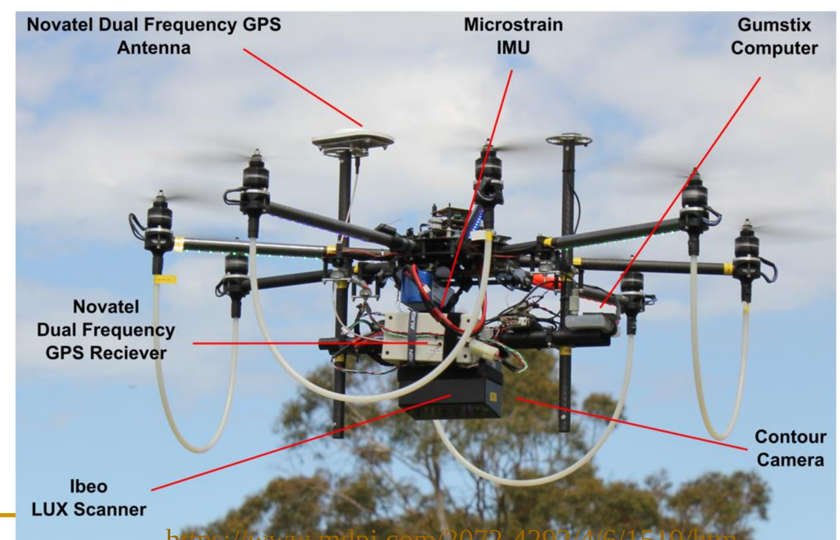


https://www.99science.com/what-is-the-accelerometer-used-for-in-mobile-devices/

Motion Tracking Applications



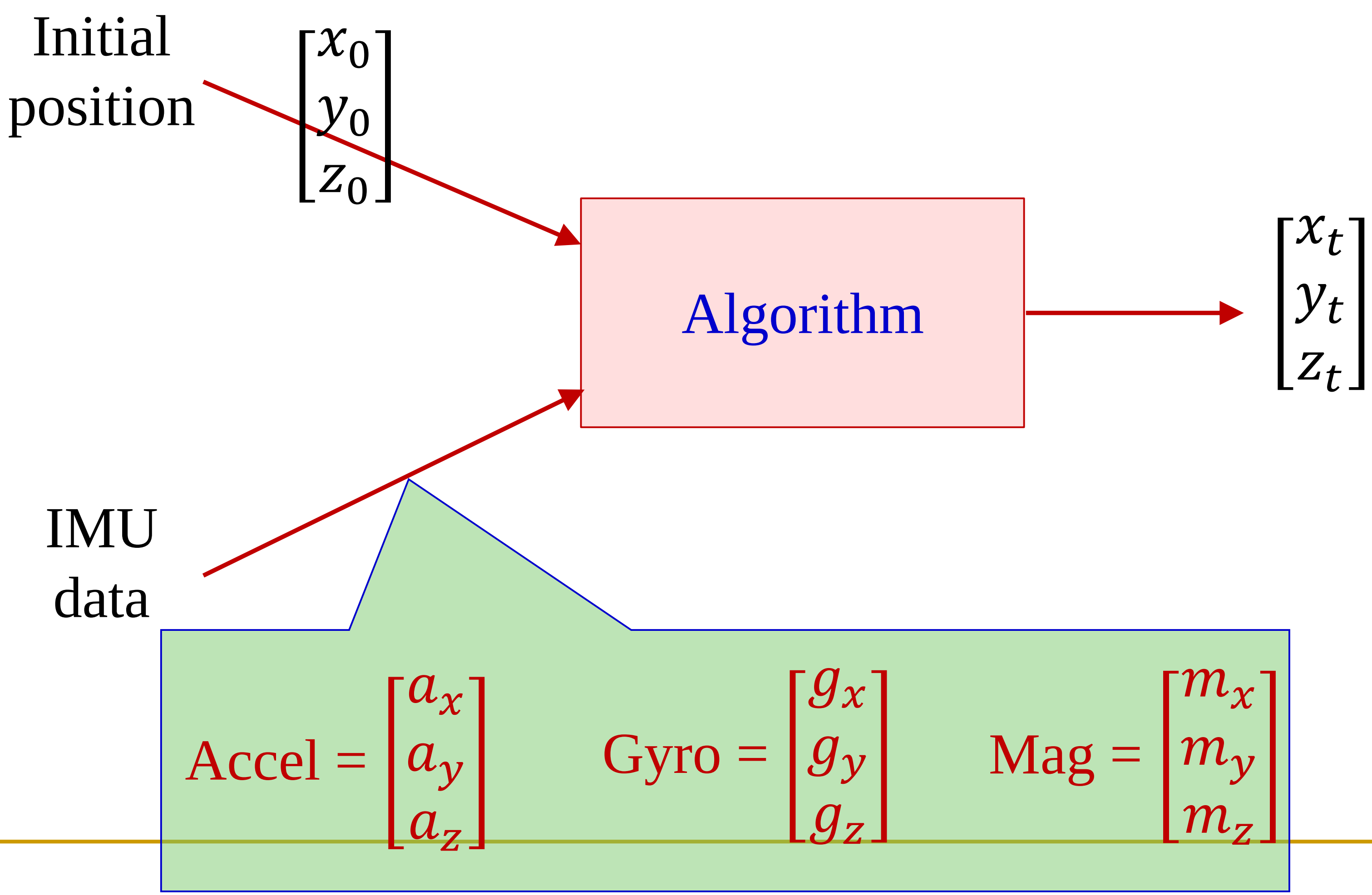




https://www.mdpi.com/2072-4292/4/6/1519/htm
https://www.nature.com/articles/s41467-020-19424-2
https://www.semanticscholar.org/paper/Reviews-on-Various-Inertial-Measurement-Unit-(IMU)-Ahmad-Ghazilla/4e189da5f9798a2a1caabd3dfb96ff794768a625

Motion Tracking Problem Formulation

- Suppose we want to track the trajectory of a drone from its IMU data



Let' see why this problem is so complicated

Simple Case: No Rotation

$$v_x = \int_0^t a_x \, . dt$$

$$d_x = \int_0^t v_x \, . dt \quad \rightarrow d_x = \int_0^t \int_0^t a_x \, . dt$$

Initial position

$$\begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix}$$

IMU data

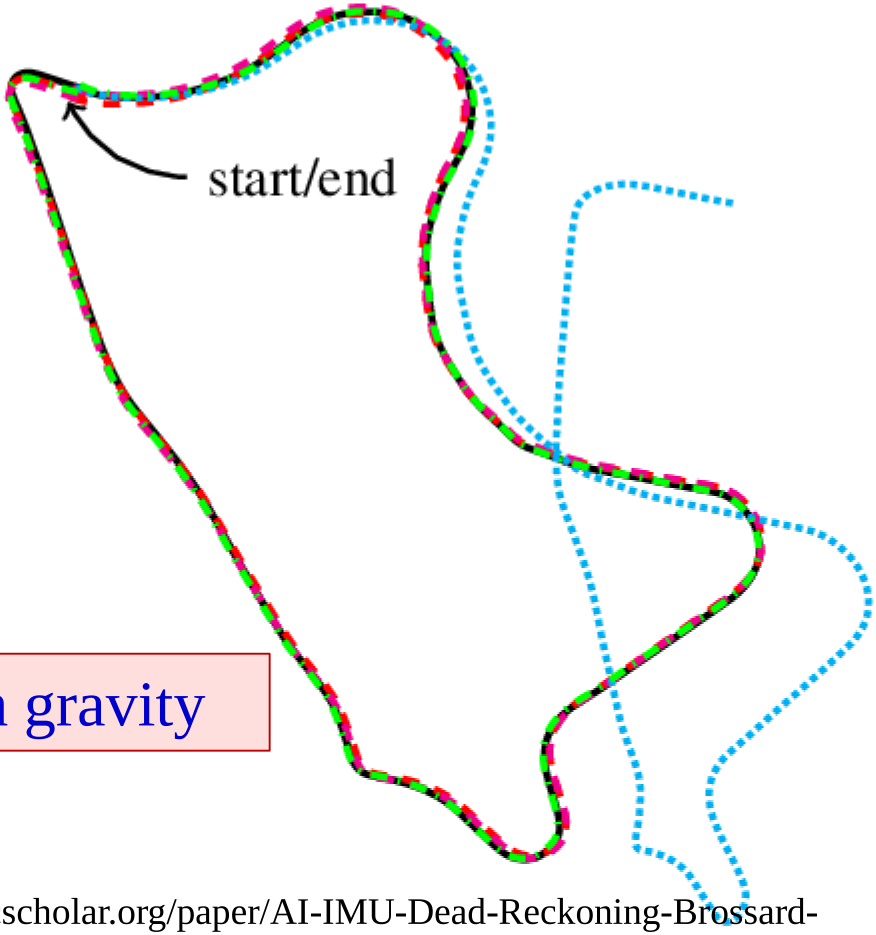
$$\begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} + \int_0^t \int_0^t a_x \, . dt \rightarrow \begin{bmatrix} x_t \\ y_t \\ z_t \end{bmatrix}$$

Simple Case: No Rotation

$$v_x = \int_0^t a_x \, . dt$$

$$d_x = \int_0^t v_x \, . dt \quad \rightarrow d_x = \int_0^t \int_0^t a_x \, . dt$$

$$d_x = \int_0^t \int_0^t (a_x + noise) \, . dt$$



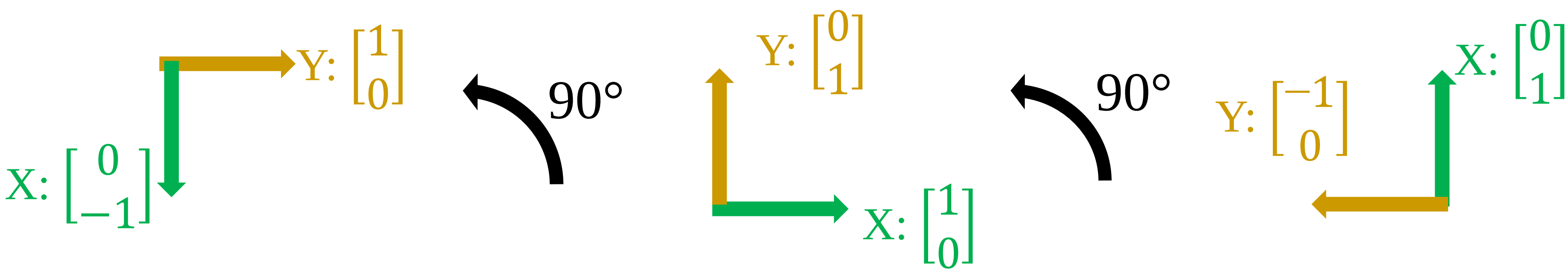
Error accumulates over time

Accelerometer values are mixed with gravity

https://www.semanticscholar.org/paper/AI-IMU-Dead-Reckoning-Brossard-Barrau/c80a0c6fcdadc1afe848d7089a314192897f3ab1

What if the Motion Includes Rotation also?

Let's model rotation using $Ax = b$ form



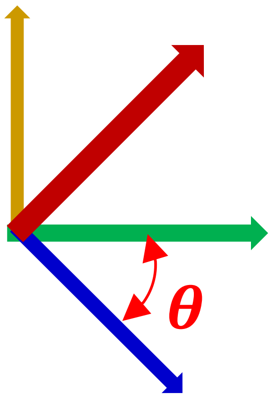
$$\begin{bmatrix}\cos 90° & -\sin 90° \\ \sin 90° & \cos 90°\end{bmatrix}\begin{bmatrix}0 & 1\\ -1 & 0\end{bmatrix} = \begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}$$

$$\begin{bmatrix}\cos 90° & -\sin 90° \\ \sin 90° & \cos 90°\end{bmatrix}\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix} = \begin{bmatrix}0 & -1\\ 1 & 0\end{bmatrix}$$

Mapping Local Coordinate to Global Coordinate

- So whatever acceleration values we are getting is w.r.t. the IMU's local coordinate system
  - How to map it to the global coordinate system?

- Let's first assume that we know the IMU **orientation** w.r.t the global axis



$$\begin{bmatrix} x_G \\ y_G \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x_S \\ y_S \end{bmatrix}$$

What if the Motion Includes Rotation also?

For 3D the rotation matrix is

$$R = R_x(\alpha)R_y(\beta)R_z(\gamma)$$

$$= \begin{bmatrix} \cos\alpha\cos\beta & \cos\alpha\sin\beta\sin\gamma - \sin\alpha\cos\gamma & \cos\alpha\sin\beta\cos\gamma + \sin\alpha\sin\gamma \\ \cos\alpha\cos\beta & \sin\alpha\sin\beta\sin\gamma + \cos\alpha\cos\gamma & \sin\alpha\sin\beta\cos\gamma - \cos\alpha\sin\gamma \\ -\sin\beta & \cos\beta\sin\gamma & \cos\beta\cos\gamma \end{bmatrix}$$

But how to find out the IMU orientation w.r.t. the global coordinate?

How to Get The 3d Orientation?

- **Method1:** Using accelerometer and magnetometer

Measures acceleration

Measures magnetic north

- What rotation is needed so that
  - Gravity is along the z axis
  - Magnetic north is along the y axis?

$$\begin{bmatrix} 3x3 \\ rotation \\ matrix \end{bmatrix} \begin{bmatrix} a_x & m_x \\ a_y & m_y \\ a_z & m_z \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & M \\ 9.8 & 0 \end{bmatrix}$$

Works well when the IMU is static

When object is moving → gravity measurement is polluted with acceleration

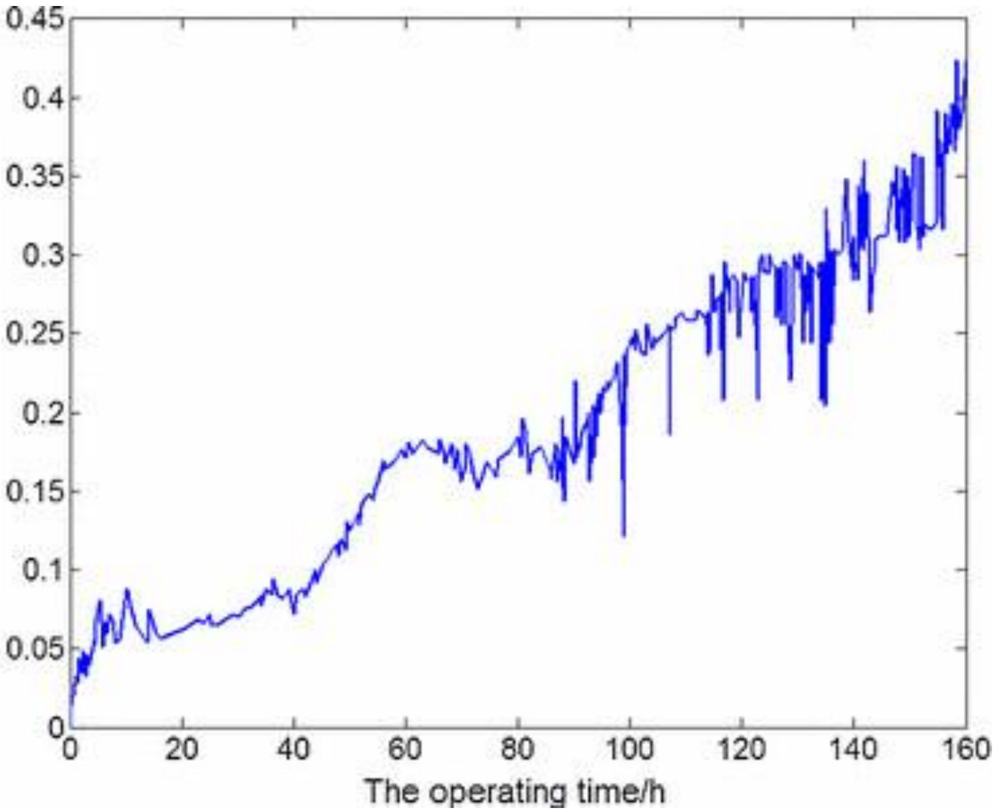
How to Get The 3d Orientation?

- **Method2:** Using gyroscope
  - Assume that we know the initial orientation

$$\theta_t = \theta_{t-1} + \int_0^t \omega_t \ .dt$$

$$\theta_t = \theta_{t-1} + \int_0^t (\omega_t + noise) \ .dt$$

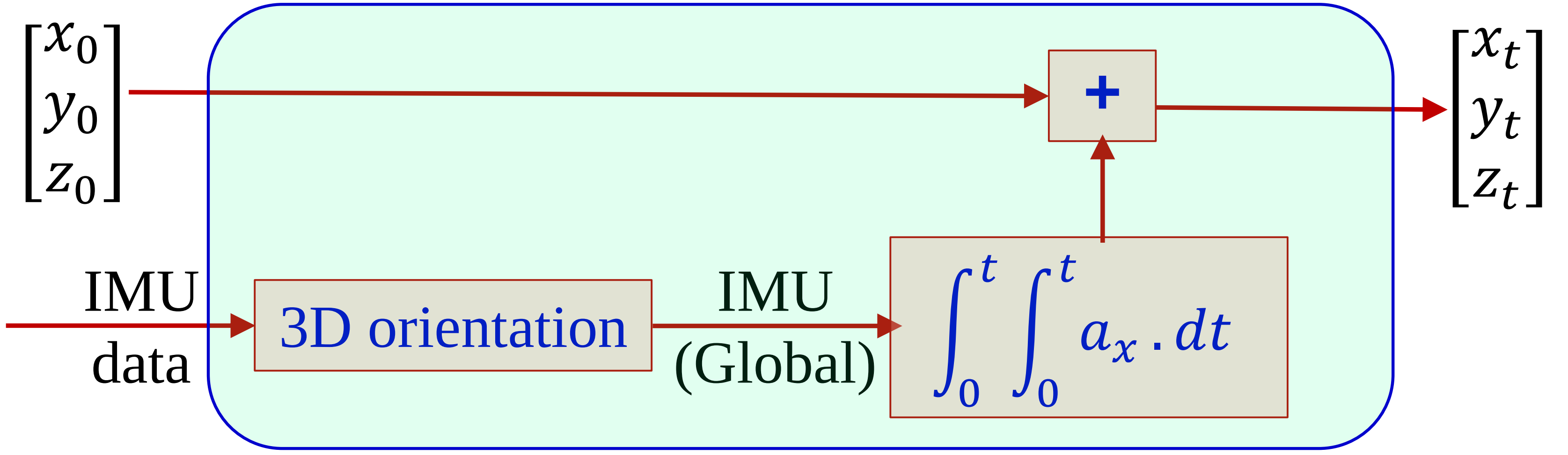
Error accumulates over time



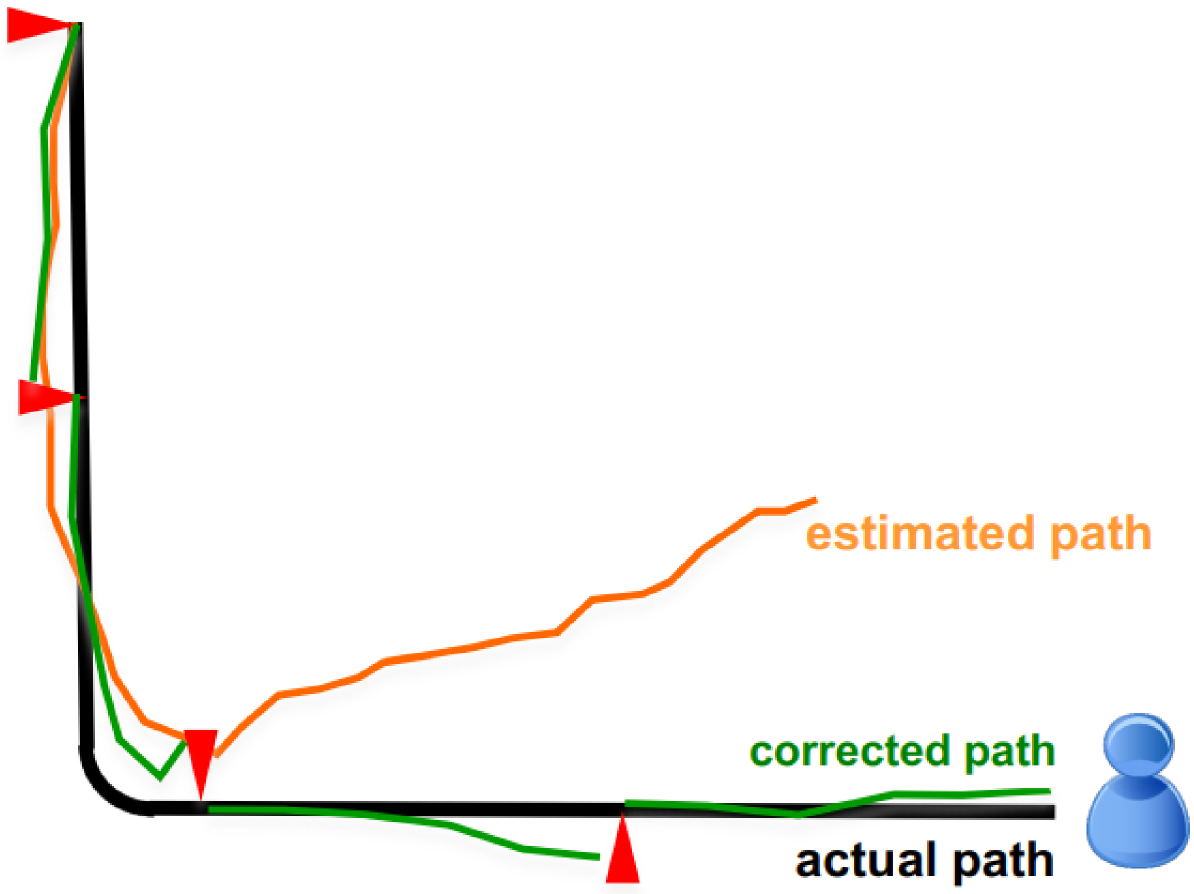
https://www.researchgate.net/figure/Drift-data-of-a-gyroscope-within-a-period-of-time_fig5_305485580

Overall Algorithm

- Someone can use a mixture of **Method1** and **Method2**
  - While static give preference to Method1
  - While moving give preference to Method2



Path Estimation Error Accumulation



Our Experimental Outcome