

NAVİGASYON DERECELİ ATALETSEL ÖLÇÜ BİRİMİ İLE BAZI JEODEZİK PARAMETRELERİ DOĞRUDAN BELİRLENMESİ



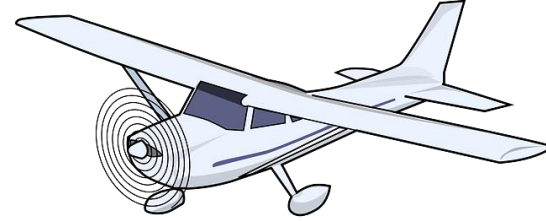
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Ataletsel Navigasyon Sistemleri

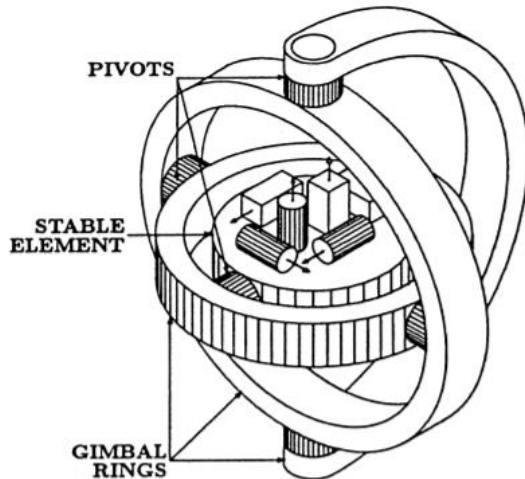


Ataletsel Navigasyon Sistemleri

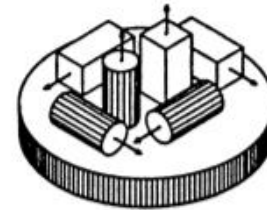
Platform
(İvmeölçer oryantasyonu)

Stabil
Platform

Analitik
(Strapdown)
Platform



**SENSOR CLUSTER OF
3 ACCELEROMETERS
3 GYROSCOPES**



**MOUNTED ON COMMON
RIGID BASE ATTACHED
TO HOST VEHICLE**

Ataletsel Navigasyon Sistemleri

İnersiyel Sensör (IMU) Hataları

$$\tilde{\mathbf{f}}^b = \mathbf{b}_a + \mathbf{M}_a \mathbf{f}^b + \mathbf{w}_a \rightarrow \text{İvmeölçer}$$
$$\tilde{\boldsymbol{\omega}}^b = \mathbf{b}_g + \mathbf{M}_g \boldsymbol{\omega}^b + \mathbf{w}_g \rightarrow \text{Jiroskop}$$

- Atım (Bias) \rightarrow Statik + Dinamik
- Ölçek (Scale)
- Yanlış Hizalama/Çapraz Çiftleme (Misalignment/Cross-Coupling)
- Rastlantısal Gürültü (Random Noise)

Kategori

- Tüketici
- Taktik
- **Navigasyon**
- Deniz

Konum Hatası

- 1-3 km/dk
- 10-40 km/saat
- **1-4 km/saat**
- <2 km/gün

Kullanım Alanları

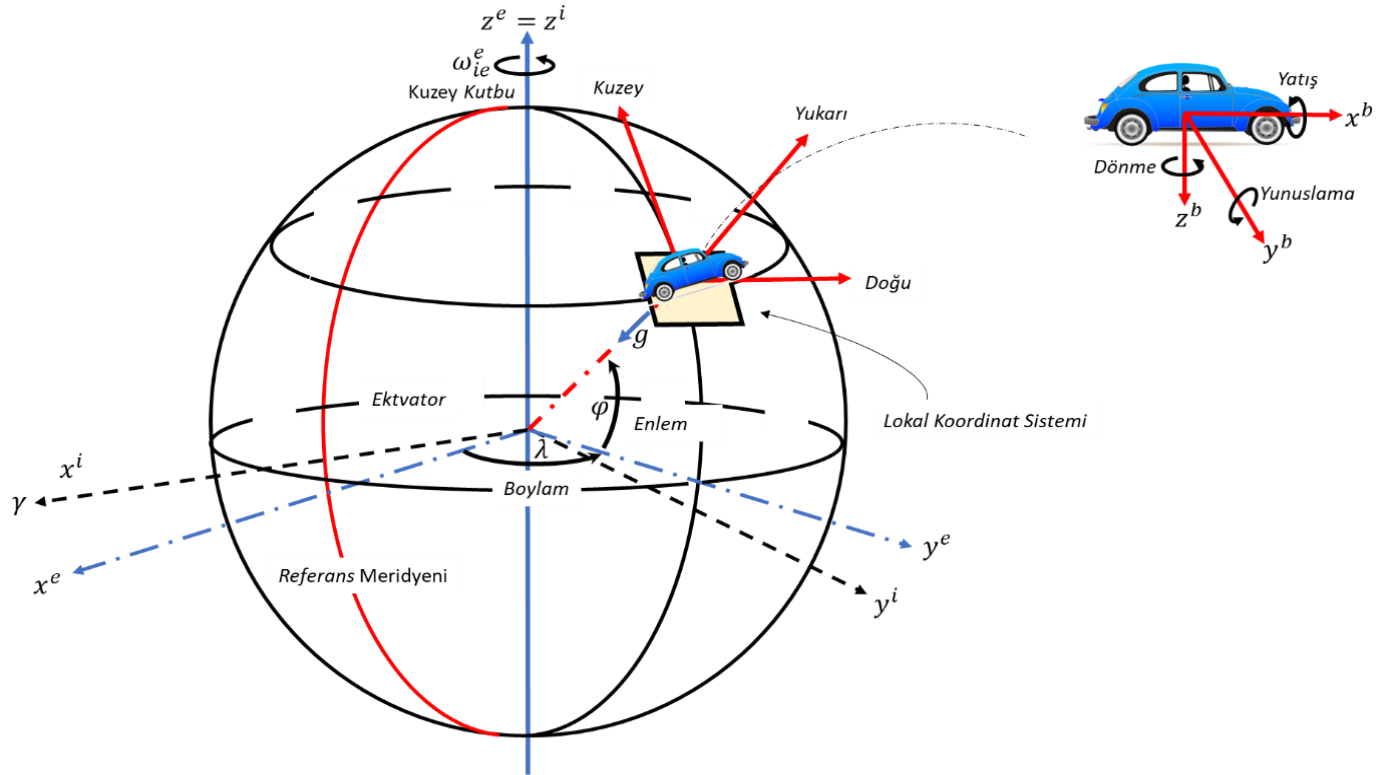
- Akıllı telefon, airbag
- Gülümlü silah, UAV
- Ticari ve askeri uçak
- Denizaltı, kıtalararası balistik füze, uzay araçları

Koordinat Çerçeveleri

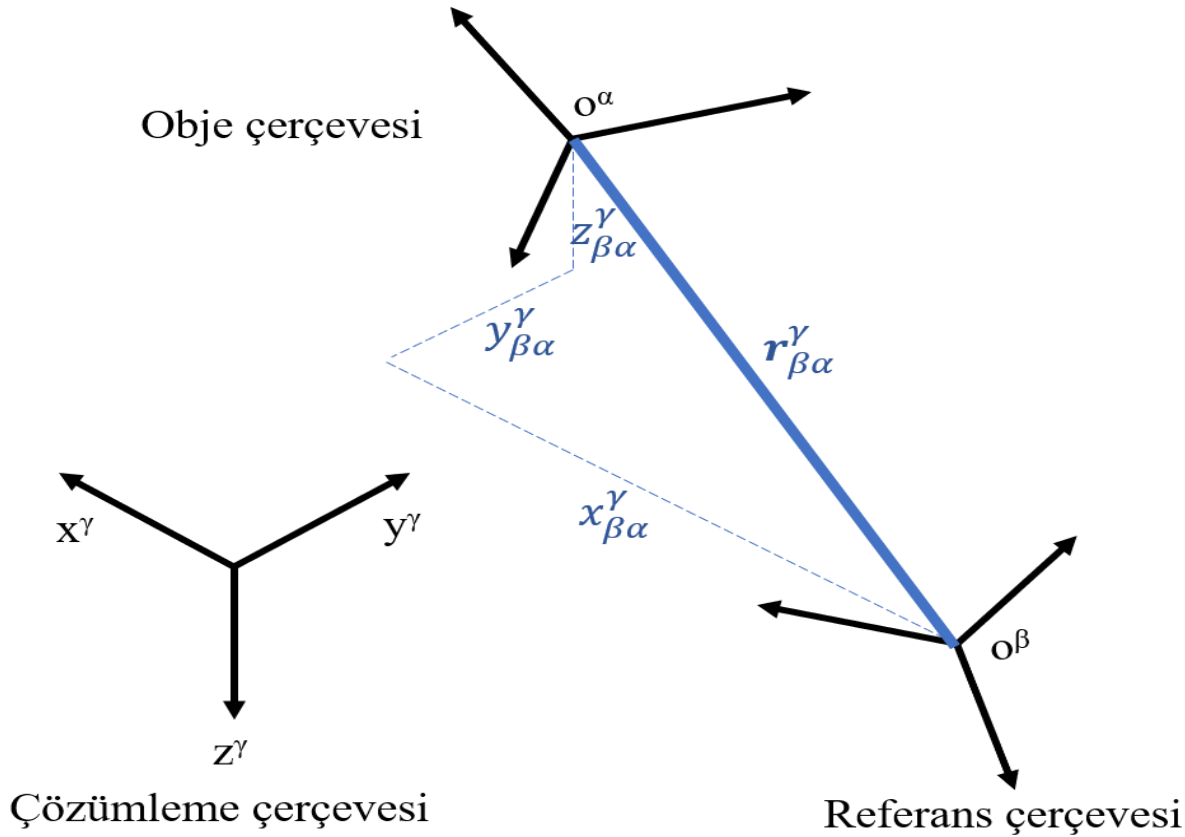
Koordinat Sistemleri

- ECI (Yer Merkezli İnersiyel - X_i, Y_i, Z_i)
- ECEF (Yer Merkezli Yer Sabit - X_E, Y_E, Z_E)
- NED (Toposentrik Lokal - Kuzey, Doğu, Düşey)
- FRD (Gövde – Burun, Sağ Doğrultu, Taban)

➔ Sağ El Dik Koordinat Sistemleri



Ataletsel Navigasyon Sistemleri



$$r_{ib}^b$$

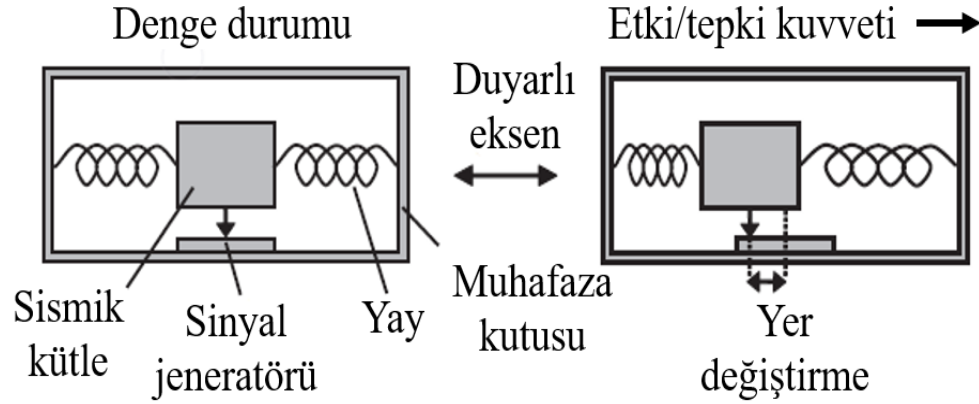
$$v_{ib}^b$$

$$f_{ib}^b$$

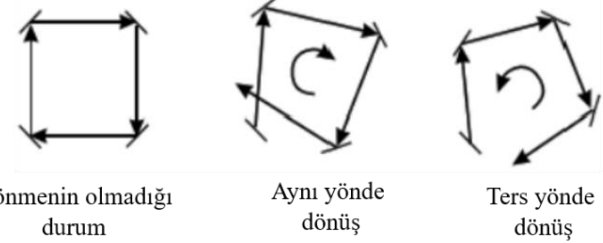
$$\omega_{ib}^b$$

$$f_{ib}^n = C_b^n f_{ib}^b$$

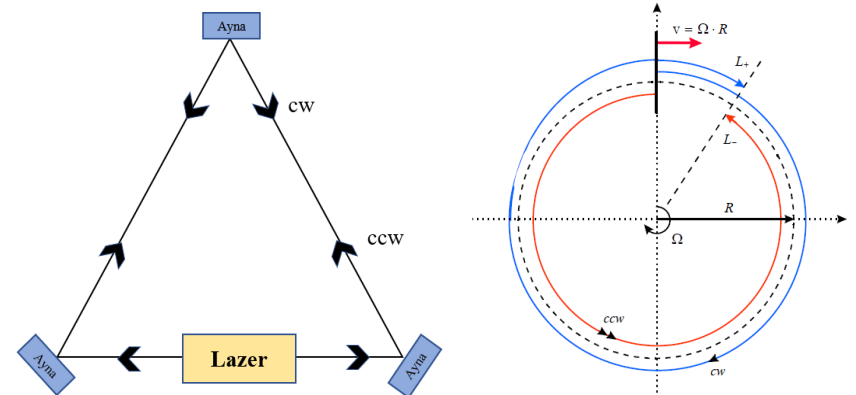
Sensörler



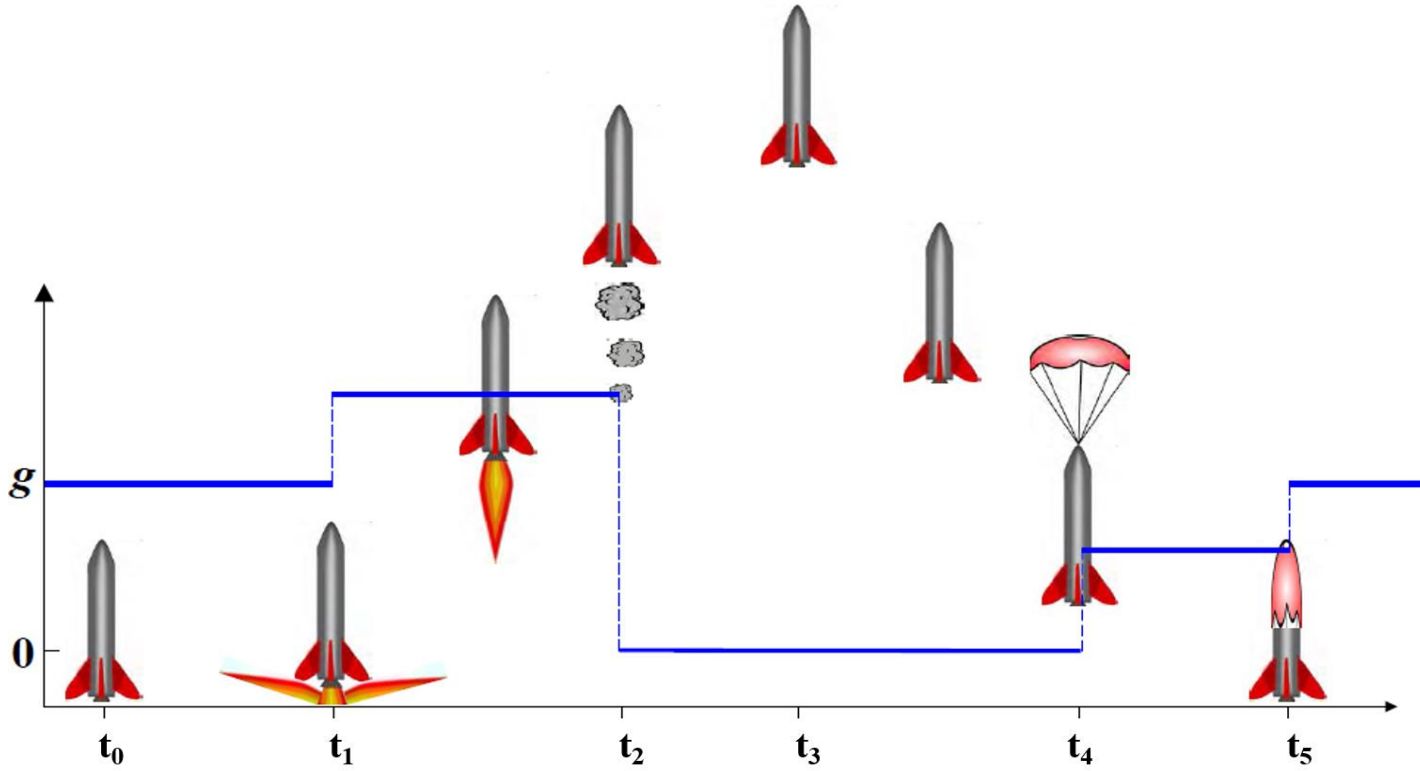
Basit ivmeölçer Yapısı



Optik jiroskobun çalışma prensibi ve Sagnac etkisi



Sensörler



Newton hareket denklemi parametreleri ve pozitif ekseni düşey yönde olan bir ivmeölçerin hareke göre çıktısı

Ataletsel Navigasyon Sistemleri

Lokal Sistemde (NED) İnersiyel Navigasyon Eşitlikleri (Navigasyon Parametreleri)

Konum:

$$\dot{\mathbf{p}}^n = \mathbf{T}_r^p \mathbf{v}^n$$

Hız:

$$\dot{\mathbf{v}}^n = \mathbf{C}_b^n \mathbf{f}^b - (2\boldsymbol{\Omega}_{ie}^n + \boldsymbol{\Omega}_{en}^n) \mathbf{v}^n + \mathbf{g}^n$$

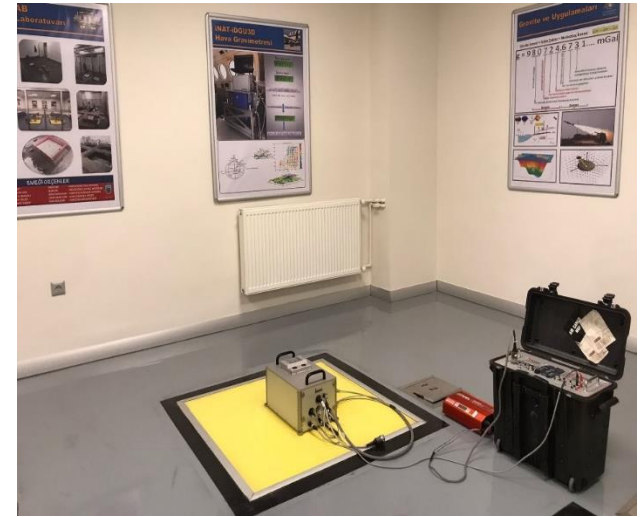
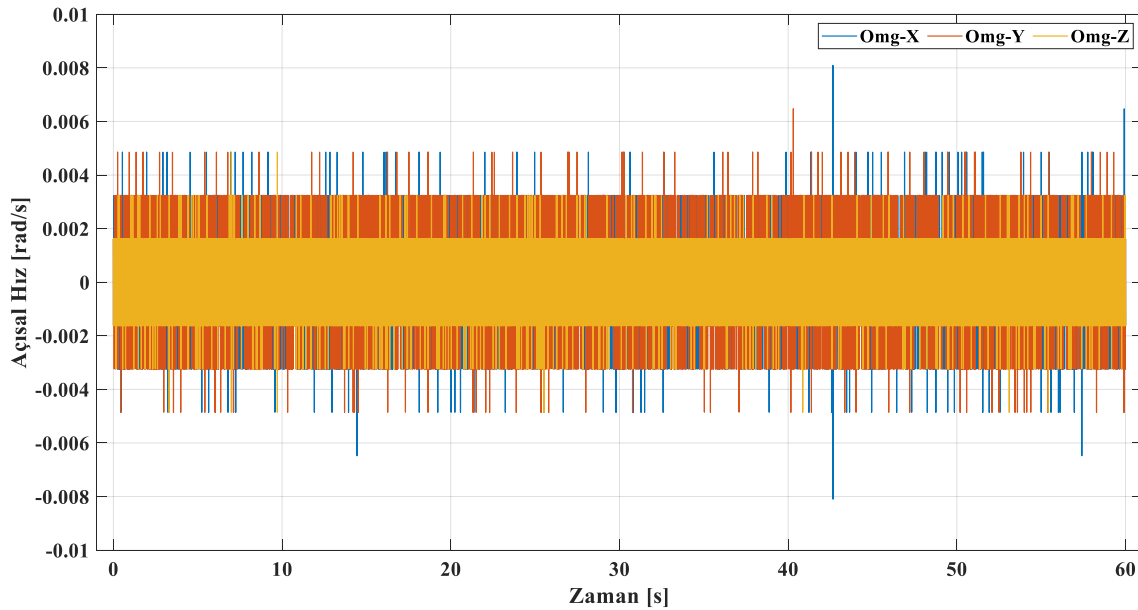
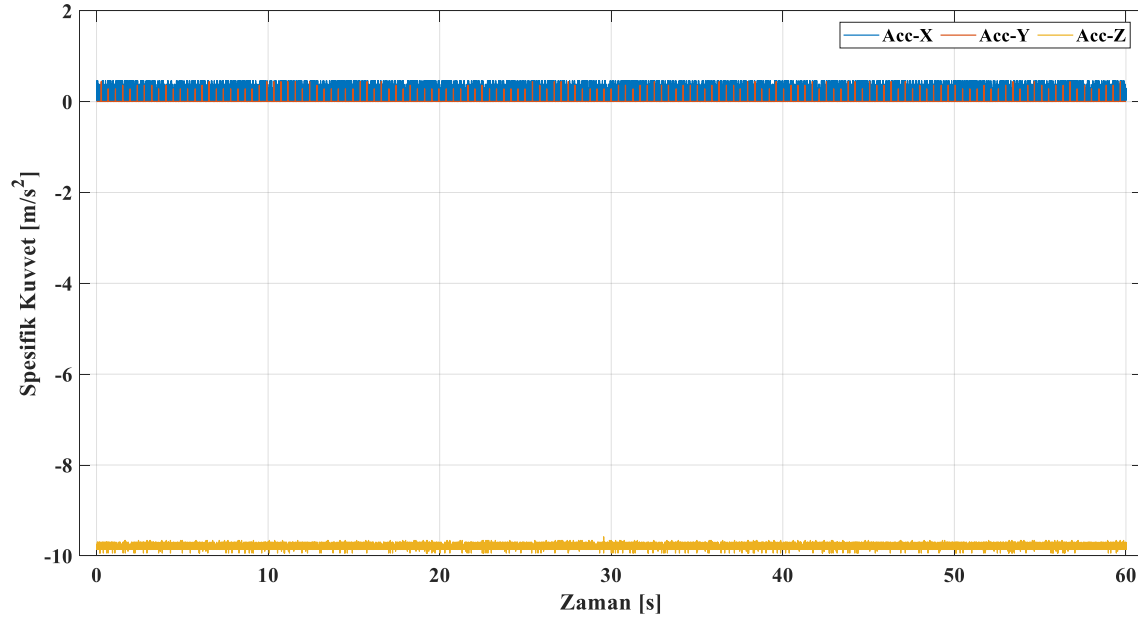
Yönelim:

$$\dot{\mathbf{C}}_b^n = \mathbf{C}_b^n \boldsymbol{\Omega}_{ib}^b - (\boldsymbol{\Omega}_{ie}^n + \boldsymbol{\Omega}_{en}^n) \mathbf{C}_b^n$$

Ataletsel Navigasyon Özellikleri

- Göreli ve sürekli konumlama
- Yüksek örnekleme (ör: 300 Hz)
- Uydu sinyalinden bağımsız
- Karıştırmaya maruz kalmaz
- Başlangıç değeri gerekir
- Zamanla konum doğruluğu düşer

Uygulama

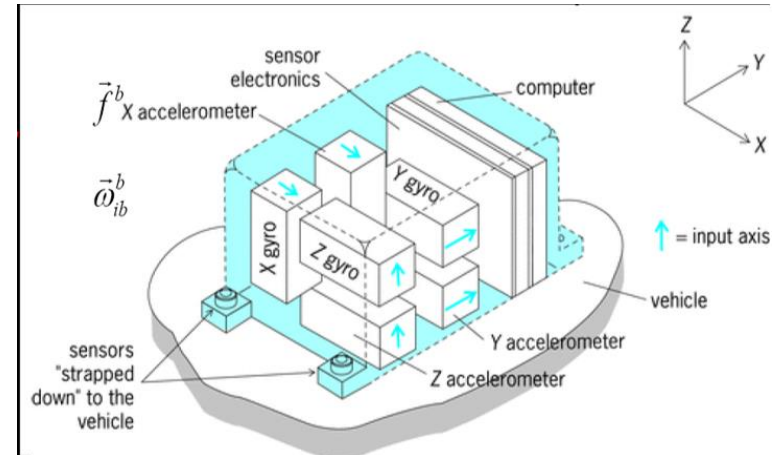


- Durağan halde 24 saatlik 4 ölçü
- 300 Hz örneklem aralığı

Uygulama



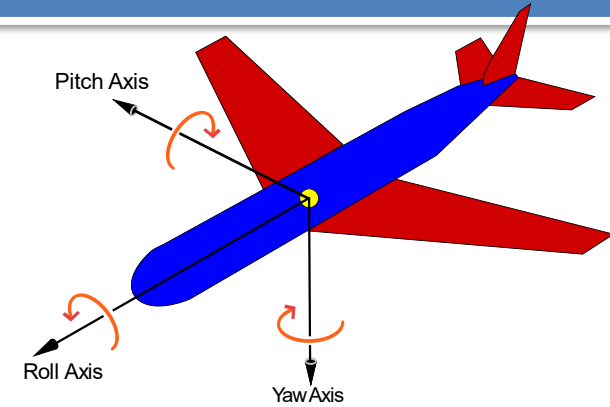
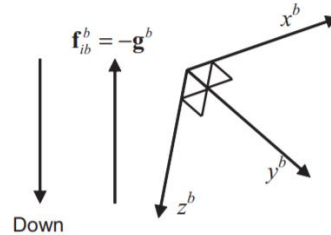
- IMU: iNAT-RQH-1001
- İvmeölçerler: QA2000- 030,
- Jiroskoplar: GG1320AN ring lazer,
- Sıcaklık sensörü,
- Entegre NovAtel GNSS alıcısı,
- PC board,
- iTembStab Sıcaklık Stabilizasyon Sistemi



Uygulama-Yatış (Roll) ve Yunuslama (Pitch) Açılarının Belirlenmesi

$$\mathbf{f}_{ib}^b = \mathbf{C}_n^b \mathbf{g}_n^b$$

$$\mathbf{g}_n^b = [0 \ 0 \ g_{b,D}]^T$$



$$\mathbf{f}_{ib}^b = \begin{bmatrix} (\cos\theta_{nb}\cos\psi_{nb}) & (\cos\theta_{nb}\sin\psi_{nb}) \\ (-\cos\phi_{nb}\sin\psi_{nb}) & (\cos\phi_{nb}\cos\psi_{nb}) \\ (+\sin\phi_{nb}\sin\theta_{nb}\cos\psi_{nb}) & (+\sin\phi_{nb}\sin\theta_{nb}\sin\psi_{nb}) \\ (\sin\phi_{nb}\sin\psi_{nb}) & (-\sin\phi_{nb}\cos\psi_{nb}) \\ (+\cos\phi_{nb}\sin\theta_{nb}\cos\psi_{nb}) & (+\cos\phi_{nb}\sin\theta_{nb}\sin\psi_{nb}) \end{bmatrix} \begin{pmatrix} 0 \\ 0 \\ g_{b,D} \end{pmatrix}$$

$$\begin{pmatrix} \mathbf{f}_{ib,x}^b \\ \mathbf{f}_{ib,y}^b \\ \mathbf{f}_{ib,z}^b \end{pmatrix} = \begin{pmatrix} (-\sin\theta_{nb}) \\ (\sin\phi_{nb}\cos\theta_{nb}) \\ (\cos\phi_{nb}\cos\theta_{nb}) \end{pmatrix} g_{b,D} \longrightarrow$$

(pitch)

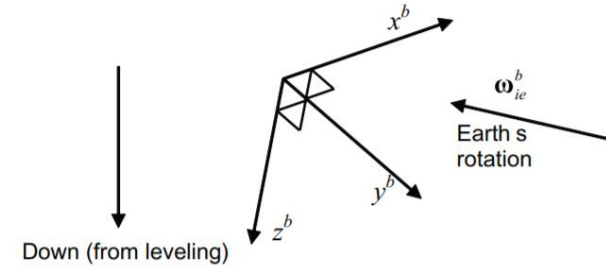
$$\theta_{nb} = \arctan\left(\frac{\mathbf{f}_{ib,x}^b}{\sqrt{\mathbf{f}_{ib,y}^b{}^2 + \mathbf{f}_{ib,z}^b{}^2}}\right)$$

(roll)

$$\phi_{nb} = \arctan(\mathbf{f}_{ib,y}^b, \mathbf{f}_{ib,z}^b)$$

Uygulama-Baş Açısının (Yaw) Açısının Belirlenmesi

$$\omega_{ib}^b = C_n^b C_e^n \begin{pmatrix} 0 \\ 0 \\ \omega_{ie} \end{pmatrix}$$



$$\omega_{ib}^b = C_n^b \begin{bmatrix} -\sin(\varphi) \cos(\lambda) & -\sin(\varphi) \sin(\lambda) & \cos(\varphi) \\ -\sin(\lambda) & \cos(\lambda) & 0 \\ -\cos(\varphi) \cos(\lambda) & -\cos(\varphi) \sin(\lambda) & -\sin(\varphi) \end{bmatrix} \begin{pmatrix} 0 \\ 0 \\ \omega_{ie} \end{pmatrix}$$

$$C_n^b \omega_{ib}^b = \begin{pmatrix} \cos(\varphi) \omega_{ie} \\ 0 \\ -\sin(\varphi) \omega_{ie} \end{pmatrix} = \begin{bmatrix} (\cos\theta_{nb} \cos\psi_{nb}) & (-\cos\phi_{nb} \sin\psi_{nb}) & (\sin\phi_{nb} \sin\psi_{nb}) \\ (\cos\theta_{nb} \sin\psi_{nb}) & (\cos\phi_{nb} \cos\psi_{nb}) & (-\sin\phi_{nb} \cos\psi_{nb}) \\ (-\sin\theta_{nb}) & (\sin\phi_{nb} \cos\theta_{nb}) & (\cos\phi_{nb} \cos\theta_{nb}) \end{bmatrix} \begin{pmatrix} \omega_{ib,x}^b \\ \omega_{ib,y}^b \\ \omega_{ib,z}^b \end{pmatrix} = \begin{pmatrix} \cos(\varphi) \omega_{ie} \\ 0 \\ -\sin(\varphi) \omega_{ie} \end{pmatrix}$$

$$\sin\psi_{nb} = -\omega_{ib,y}^b \cos\phi_{nb} + \omega_{ib,z}^b \sin\phi_{nb}$$

$$\cos\psi_{nb} = -\omega_{ib,x}^b \cos\theta_{nb} + \omega_{ib,y}^b \sin\phi_{nb} \sin\theta_{nb} + \omega_{ib,z}^b \cos\phi_{nb} \sin\theta_{nb}$$

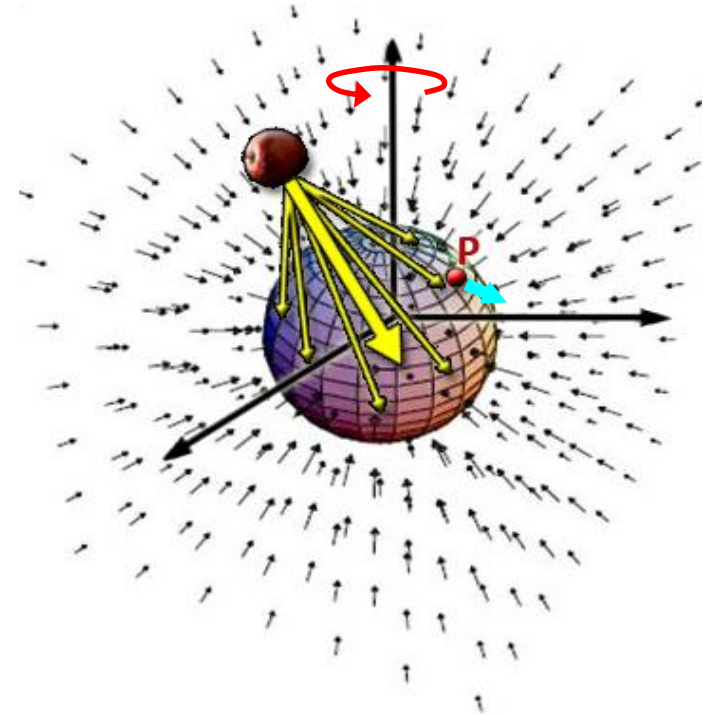
$$\psi_{nb} = \arctan(\sin\psi_{nb}, \cos\psi_{nb})$$

Uygulama-Yer Dönme Parametresinin Belirlenmesi

$$\hat{\omega}_{ie} = \sqrt{(\bar{\omega}_{ib,X}^b)^2 + (\bar{\omega}_{ib,Y}^b)^2 + (\bar{\omega}_{ib,Z}^b)^2}$$



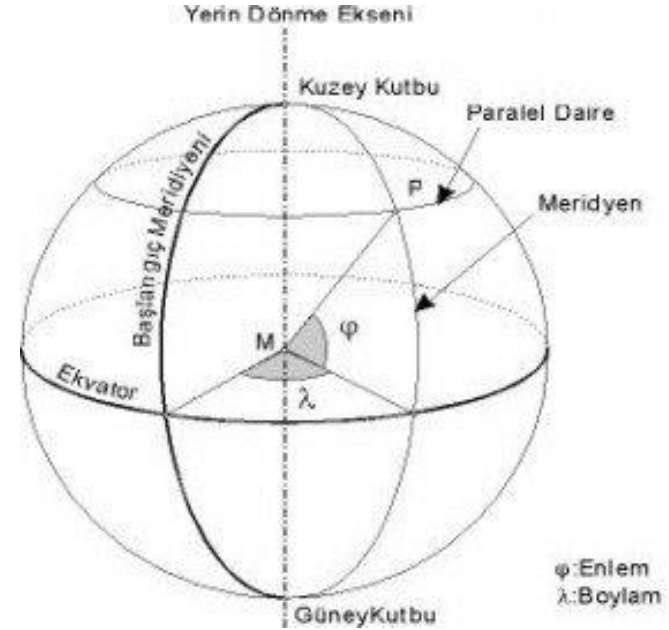
Uygulama-Lokal Gravitenin Belirlenmesi



$$\hat{g} = \sqrt{(\bar{f}_{ib,x}^b)^2 + (\bar{f}_{ib,y}^b)^2 + (\bar{f}_{ib,z}^b)^2}$$

Uygulama -Enlemin Belirlenmesi

$$\hat{\varphi}_b = \cos^{-1} \left(\frac{\sqrt{(\bar{\omega}_{ib,X}^b)^2 + (\bar{\omega}_{ib,Y}^b)^2}}{\omega_{ie}} \right)$$



Uygulama Sonuçları

Oturum	$\hat{\omega}_{ie}$ (°/h)	\hat{g} (ms ⁻²)	$\hat{\varphi}_E$ (° ' ")
1	15.03869	9.799347	39° 46' 17".52228
2	15.03943	9.799344	39° 45' 41".99524
3	15.03835	9.799355	39° 46' 05".84930
4	15.03836	9.799361	39° 46' 06".86554
ORTALAMA	15.0387075	9.79935175	39° 46' 03".05809
REFERANS DEĞER	15.0410670514	9.7991116478	39° 55' 57.56"

Teşekkür Ederiz.