IMU Requirements for Torque Vectoring in Electric Vehicles
Case Study: Vehicle Turning at 25 km/h

Contents

1 Introduction

Torque vectoring improves vehicle stability by controlling the left/right wheel torques to correct yaw motion. The controller relies heavily on accurate measurements of yaw rate and acceleration from an Inertial Measurement Unit (IMU).

If the IMU is noisy or drifting, incorrect torque commands may be generated, potentially destabilizing the vehicle. Therefore, deriving sensor accuracy requirements is essential before selecting an IMU.

This report derives:

- Required yaw-rate accuracy at 25 km/h
- Required IMU specifications
- Comparison of commercial IMUs
- Final sensor recommendation

2 Kinematic Turning and Wheel Speed Relationship

This section derives the relationship between steering angle, yaw rate and left/right wheel speeds. This is the fundamental kinematic model used in torque vectoring.

2.1 Turning Geometry

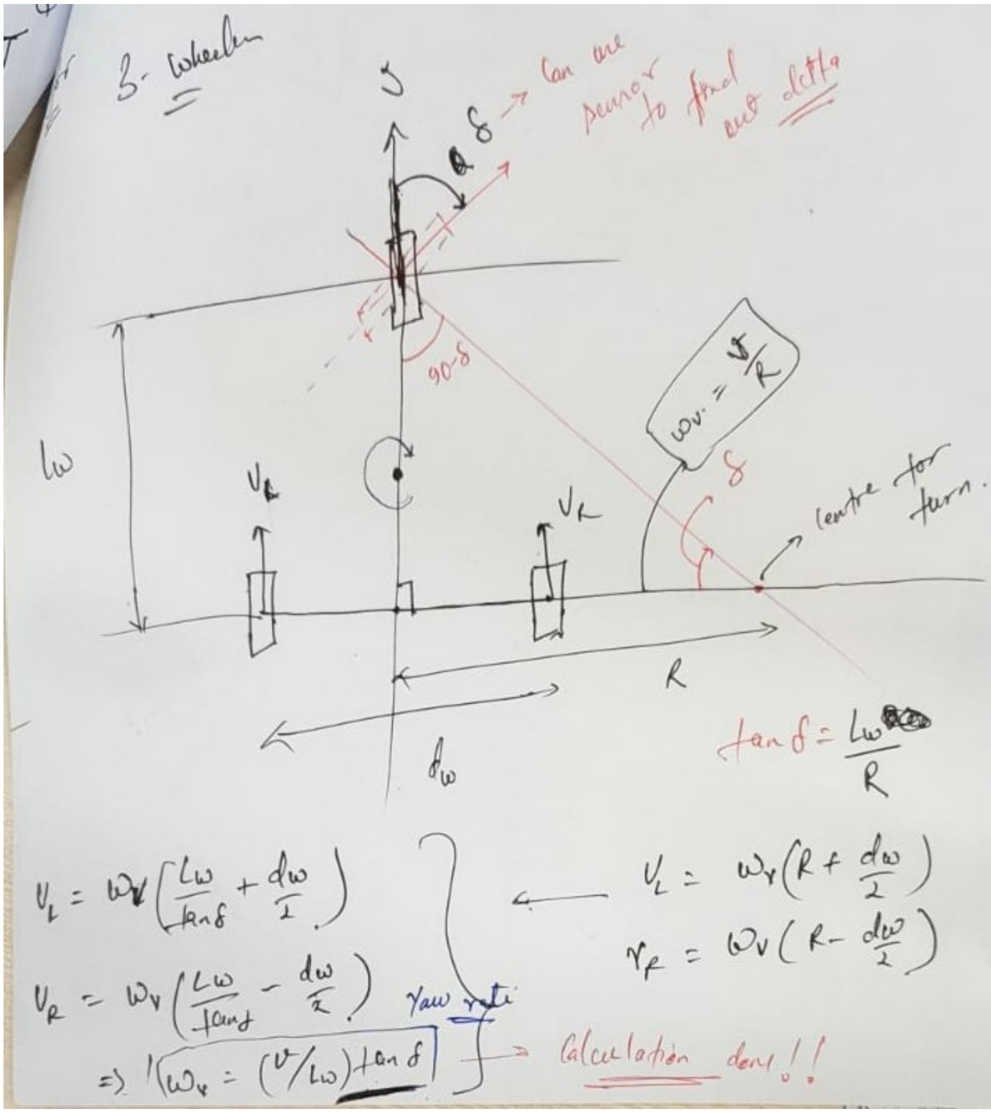

Figure 1: Hand–derived kinematic model of vehicle turning showing steering angle, turning radius and wheel velocities.

From vehicle geometry:

$$\tan\delta = \frac{L_w}{R} \tag{1}$$

	L_w	Wheelbase
Where:	R	Turning radius
	δ	Steering angle

Therefore the turning radius is:

$$R = \frac{L_w}{\tan\delta} \tag{2}$$

2.2 Yaw Rate Relationship

Yaw rate of the vehicle is:

$$\omega_v = \frac{V}{R} \tag{3}$$

Substituting R:

$$\boxed{\omega_v = \frac{V}{L_w} \tan\delta} \tag{4}$$

This is the reference yaw rate used in torque vectoring.

2.3 Left and Right Wheel Velocities

During turning, the inner and outer wheels travel along circles of different radii.

Let: d_w Track width

2.3.1 Outer Wheel Radius

$$R_{outer} = R + \frac{d_w}{2} \tag{5}$$

2.3.2 Inner Wheel Radius

$$R_{inner} = R - \frac{d_w}{2} \tag{6}$$

Wheel linear velocities become:

$$V_L = \omega_v \left(R + \frac{d_w}{2} \right) \tag{7}$$

$$V_R = \omega_v \left(R - \frac{d_w}{2} \right) \tag{8}$$

2.4 Substitute Turning Radius

Substitute $R = \frac{L_w}{\tan\delta}$:

$$\boxed{V_L = \omega_v \left(\frac{L_w}{\tan\delta} + \frac{d_w}{2} \right)} \tag{9}$$

$$\boxed{V_R = \omega_v \left(\frac{L_w}{\tan\delta} - \frac{d_w}{2} \right)} \tag{10}$$

These equations describe the required wheel speeds during a turn.

2.5 Wheel Angular Speeds

If r_w is wheel radius:

$$\omega_L = \frac{V_L}{r_w}, \quad \omega_R = \frac{V_R}{r_w} \tag{11}$$

2.6 Importance for Torque Vectoring

These equations show:

- Outer wheel must rotate faster than inner wheel.
- Torque vectoring modifies this speed difference.
- IMU yaw-rate feedback corrects deviations from this kinematic model.

This kinematic relationship forms the feedforward component of torque vectoring control.

3 Yaw rate calculation

$$r = \frac{V}{L}\tan(\delta) \tag{12}$$

r	Yaw rate (rad/s)
V	Vehicle speed (m/s)
L	Wheelbase (2.7 m assumed)
δ	Steering angle (rad)

This equation gives the reference yaw rate used by the torque vectoring controller.

4 Vehicle Speed Conversion

Given speed:

$$25 \text{ km/h}$$

$$V = 6.94 \text{ m/s}$$

5 Yaw Rate During Turning

5.1 Gentle Turn (3° steering)

$$\delta = 3^\circ = 0.052 \text{ rad}$$

$$r = \frac{6.94}{2.7} \times 0.052 = 0.134 \text{ rad/s}$$

$$r \approx 7.7^\circ/s$$

5.2 Moderate Turn (5° steering)

$$r \approx 13^\circ/s$$

5.3 Tight Turn (10° steering)

$$r \approx 26°/s$$

Key Result

$$\boxed{Yaw\ rate\ range = 8°/s \rightarrow 26°/s}$$

Low-speed driving produces small yaw rates, making sensing more challenging.

6 Yaw Error Detection Requirement

Torque vectoring reacts to yaw error:

$$r_{error} = r_{ref} - r_{meas} \tag{13}$$

Industry practice:

$$Controller\ reacts\ at\ 5\%\ yaw\ error$$

Smallest yaw rate $= 8°/s$

$$Yaw\ error_{min} = 0.05 \times 8 = 0.4°/s$$

$$\boxed{Controller\ must\ detect\ 0.4°/s}$$

7 Sensor Noise Requirement

Industry rule:

$$Sensor\ noise < \frac{1}{10} \times smallest\ detectable\ signal$$

$$Noise_{max} = \frac{0.4}{10} = 0.04°/s$$

$$\boxed{Yaw\ measurement\ noise < 0.04°/s}$$

8 Conversion to Datasheet Specification

IMU datasheets specify noise density in:

$$°/s/\sqrt{Hz}$$

Control bandwidth $\approx$ 50 Hz.

$$\sigma = N\sqrt{BW}$$

$$N\sqrt{50} < 0.04$$

$$\boxed{N < 0.0057°/s/\sqrt{Hz}}$$

9 Final IMU Requirements

Parameter	Requirement
Gyro noise density	$\leq 0.006°/s/\sqrt{Hz}$
Gyro bias stability	$\leq 1°/hr$
Sampling rate	$\geq$ 200 Hz
Gyro range	$\pm 250°/s$
Accelerometer bias	$\leq 50\mu g$

These correspond to automotive-grade IMU specifications.

10 IMU Classes Overview

Class	Typical Use
Hobby	Arduino, DIY
Consumer	Drones, phones
Industrial	Robotics, research EV
Automotive	Real EV / ADAS
Navigation	Aerospace / autonomy
Reference INS	Vehicle testing labs

11 Class 1 – Hobby IMUs

Sensor	Noise	Bias	Cost
MPU6050	0.03	50°/hr	150

Fails requirement by 5×.

Not suitable for torque vectoring.

12 Class 2 – Consumer IMUs

Sensor	Noise	Bias	Cost
ICM-42688	0.015	10°/hr	3000

Fails requirement by 2–3×.

Suitable only for simulation or robotics.

13 Class 3 – Industrial IMUs

Sensor	Noise	Bias	Cost
ADIS16470	0.008	8°/hr	40k– 60k
ADIS16465	0.006	6°/hr	65k
ADIS16507	0.005	3°/hr	88k

Borderline but usable.

- ADIS16470: `https://www.digikey.in/en/products/detail/analog-devices-inc/ADIS16470-PCBZ/7932981`
- ADIS16507: `https://www.digikey.in/en/products/detail/analog-devices-inc/ADIS16507-3-PCBZ/11642789`

14 Class 4 – Automotive IMUs

Sensor	Noise	Bias	Cost
VectorNav VN100	0.0035	5°/hr	45k– 60k
Xsens MTi-610	0.003	0.6°/hr	60k– 1L
Xsens MTi-680	0.002	0.3°/hr	1.1L

These meet torque vectoring requirements.

Purchase links:

- VectorNav VN100: `https://www.vectornav.com/products/detail/vn-100`
- Xsens MTi-610: `https://www.xsens.com/sensor-modules/xsens-mti-610r-imu`
- Xsens MTi-680: `https://www.xsens.com/sensor-modules/xsens-mti-680G-rtk-gnss-ins`

15 Navigation Grade IMUs

Sensor	Noise	Bias	Cost
Honeywell HG4930	0.001	0.05°/hr	8L
KVH 1750	0.002	0.05°/hr	7L

10× better than required.

16 Reference Paper for the use of IMU sensor

Active and Passive Control Strategies for Ride Stability and Handling Enhancement in Three-Wheelers

by Dumpala Gangi reddy and Dr. Krishnakumar R, IIT MADRAS

The work in this paper directly relates to my work for developement to Torque vectoring in our vehicle and the IMU sensor used.

16.1 Use of ADMA-GNSS/INS for Controller Development

Driver Input → Vehicle → ADMA Measurement → Model Validation → Controller Design → Production Sensors

The ADMA system acts as a high-accuracy reference platform enabling model validation, controller tuning, and performance verification of the torque vectoring control system.

System	Accuracy	Cost
GeneSys ADMA-G ECO	0.025° heading	15–20L
GeneSys ADMA-G Pro	0.015° heading	25–40L

Buy: `https://genesys-offenburg.de/en/adma-g/`

17 Complete Cost Ladder

Table 1: Complete IMU Comparison for Torque Vectoring Applications

Class	**Sensor**	**Gyro Noise** ($^\circ/s/\sqrt{Hz}$)	**Bias Stability** ($^\circ/hr$)	**Approx Cost**
Hobby	MPU6050	0.03	50	150
Consumer / Drone	ICM-42688	0.015	10	3,000
Industrial	ADIS16470	0.008	8	40k– 60k
Industrial	ADIS16465	0.006	6	65k
Industrial	ADIS16507	0.005	3	88k
Automotive	VectorNav VN100	0.0035	5	45k– 60k
Automotive	Xsens MTi-610	0.003	0.6	60k– 1L
Automotive	Xsens MTi-680	0.002	0.3	1.1L
Navigation Grade	Honeywell HG4930	0.001	0.05	8L
Navigation Grade	KVH 1750	0.002	0.05	7L
Reference INS	GeneSys ADMA-G ECO	0.0005	0.02	15–20L
Reference INS	GeneSys ADMA-G Pro	0.0003	0.01	25–40L

18 Procurement and Delivery Considerations

This section compares delivery timelines for VectorNav and Analog Devices IMUs for procurement in India and provides final purchase recommendations.

18.1 VectorNav VN-100 Procurement (USA Based)

VectorNav products are exported from the United States via authorized distributors. Typical procurement:

Estimated delivery time to India:

6–10 weeks

Official purchase links:

- Product Page / Request Quote:
  VectorNav VN-100 Product Page

Conclusion: VectorNav procurement involves export logistics and longer delivery times.

18.2 Analog Devices IMU Procurement (India Distributors)

Analog Devices IMU sensor is a Borderline but usable for the current experimental setup and also currently available.

Typical delivery time: 4–7 days

Purchase Links:

- DigiKey:
  ADIS16470-PCBZ Evaluation Board

(stock available)

Recommended for project timeline: Analog Devices IMU-ADIS16470 (40k– 60k)