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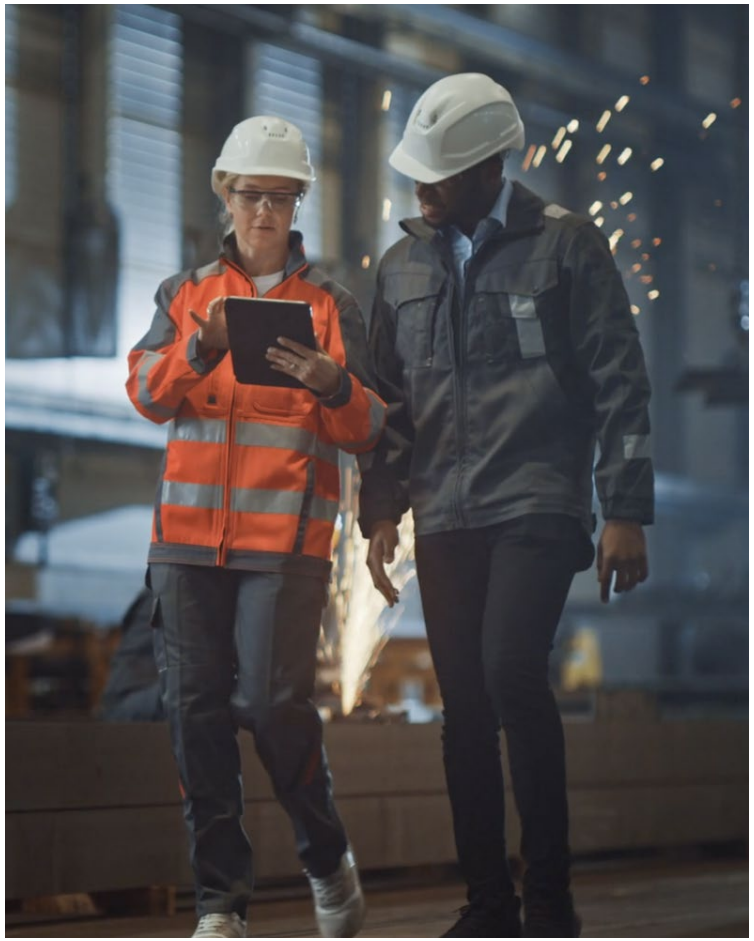
For additional Materials and Information.

Attracting Tomorrow

TDK

SmartIndustrial™ | MEMS Motion



Vamshi Gangumalla

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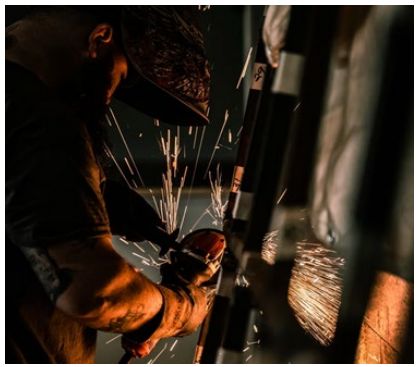
Industrial IMU use case examples

- **Navigation use case -**
  - Applies to GNSS modules, Construction/Agricultural Vehicle, Drone, Mobile Robots

- **Tilt Sensing use case -**
  - Applies to Survey, Construction/Agricultural vehicle, Robots, Platform stabilization



- **Vibration Sensing use case -**
  - Applies to Industrial motors, Robots (servo motor control)

Industrial Motion Sensing Applications

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Construction Vehicles
Navigation, tilt sensing, positioning

Precision Agriculture
Navigation, tilt sensing, positioning

Survey Equipment
Positioning, Stabilization

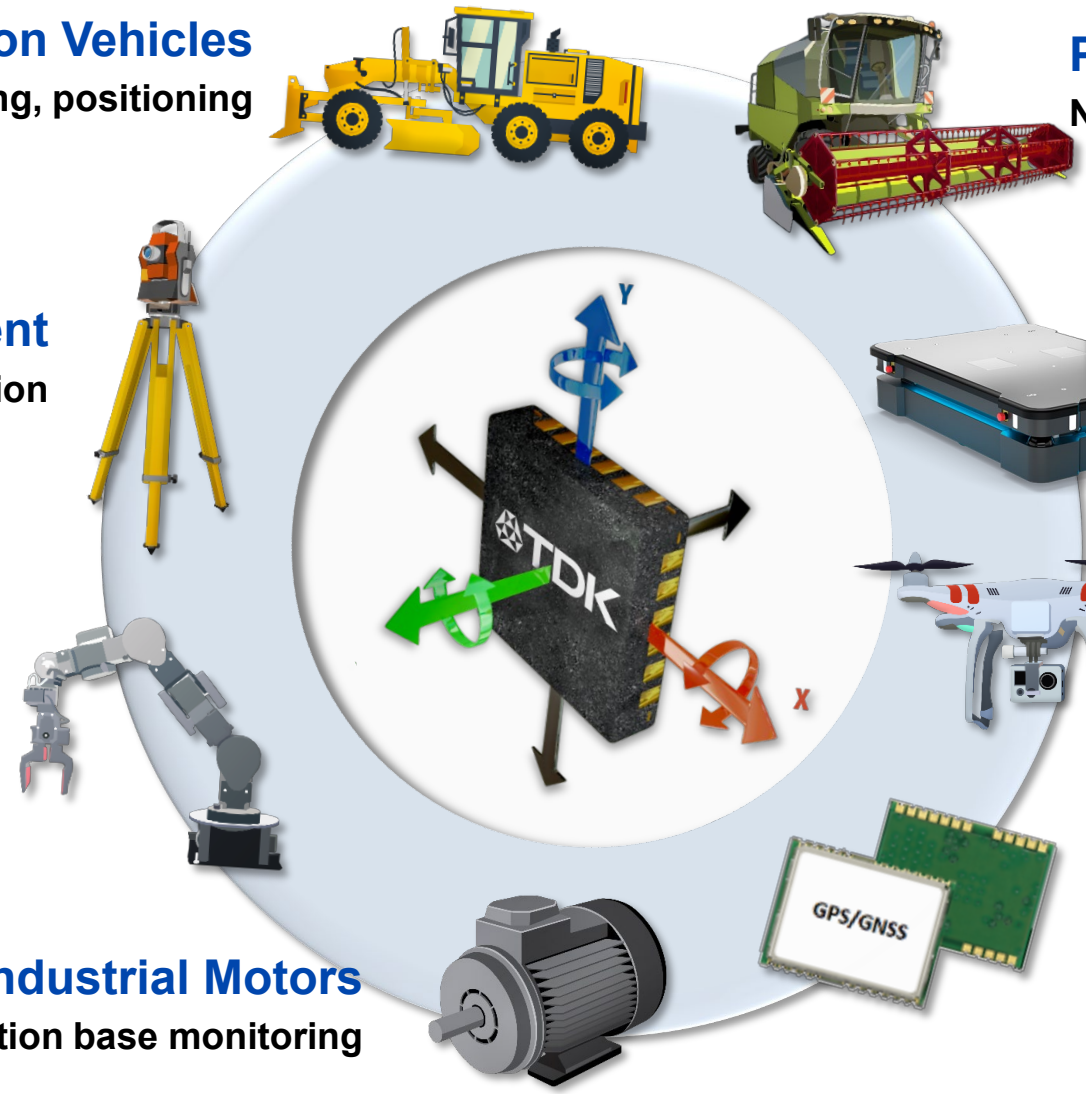
AMR – Autonomous Mobile Robot
Navigation, Dead Reckoning

Agricultural and Industrial Drones
Navigation, Stabilization

Industrial Robots, AGV
Navigation, Stabilization

GNSS Module
Dead Reckoning & High Precision Positioning

Industrial Motors
Condition base monitoring



TDK InvenSense Industrial Motion Sensing Value Proposition

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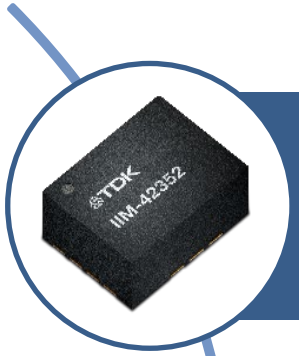


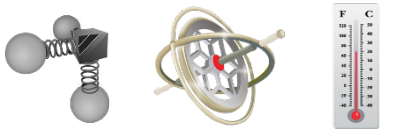
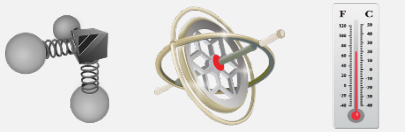
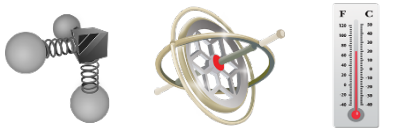
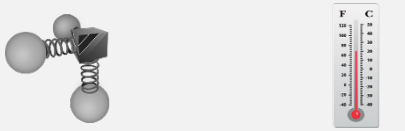
SmartIndustrial™ Portfolio - Offering a broad range of cost vs performance choices

High performance IMU modules with Fault Tolerance, Factory Calibration and Timestamping capabilities

Wide operating temperatures

TDK SmartIndustrial™ Portfolio

Attracting Tomorrow TDK

Sensors	Family	Parts	Description
 Accel Gyro Temp	High-Performance IMU modules	IIM-46234	Fault tolerant, High accuracy, low noise Factory calibrated for high thermal stability (Sampling now)
		IIM-46230	
 Accel Gyro Temp	Mid-Range IMU Devices	IIM-20670	High thermal stability, Extended temp (-40° to 105°C) (Sampling now)
 Accel Gyro Temp	Compact IMUs	IIM-42652	Low power consumption, small form factor, Extended temp (-40° to 105°C)
 Accel Temp	3-axis Accelerometer	IIM-42352	Low noise, vibration sensing up to 4Khz, Extended temp (-40° to 105°C)
		IIM-42351	Low noise tilt sensing, compact, Extended temp (-40° to 105°C)

IIM-42652 - 6-axis SmartIndustrial™ MotionTracking

IIM-42652 Compact 6-axis IMU
Low power, Extended Temperature Range

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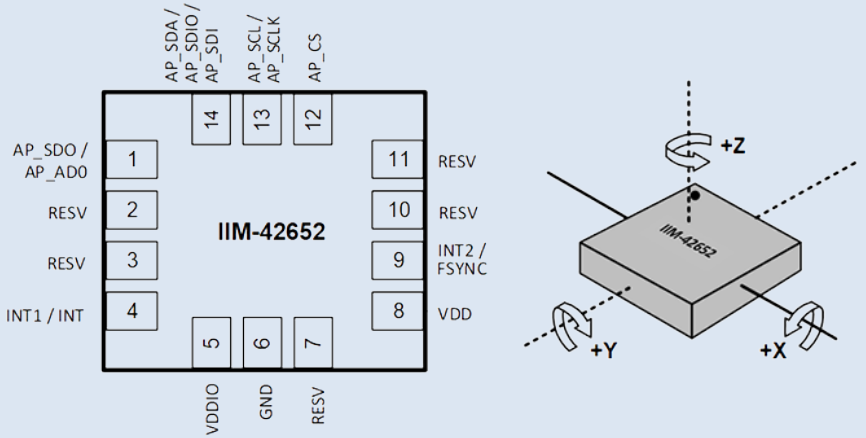
Features

- Digital-output X-, Y-, and Z-axis angular rate sensors (gyroscopes) with programmable full-scale range of from ±15.625 to ±2000 degrees/sec
- Digital-output X-, Y-, and Z-axis accel with programmable FSR of ±2g, ±4g, ±8g and ±16g
- Digital-output temperature sensor
- Supports SPI and I2C
- 20,000 g shock tolerant
- MEMS structure hermetically sealed and bonded at wafer level

Parameter	Min	Typ	Max	Unit
GYROSCOPE				
Full scale Range	±15.625		±2000	°/sec
Sensitivity Error Over Temperature	-0.02	±0.005	+0.02	%/°C
Offset Error Over Temperature	-0.025	±0.02	0.025	dps/°C
Noise Density		0.0038	0.007	°/sec/√Hz
ACCELEROMETER				
Full scale Range	±2		±16	*g*
Sensitivity Error Over Temperature	-0.025	±0.005	0.025	%/°C
Offset Error Over Temperature	-0.4	±0.15	0.4	mg/°C
Noise Density		70	100	µg/√Hz
Output data rate	1.5625		32000	Hz



Advantages

- Operating Temperature Range of -40°C to 105°C
- Ability to provide external clock to synchronize with the system
- Low noise
- Low power
- Compact: 2.5 x 3 x 0.91 mm (14-pin LGA)

Autonomous Agricultural Equipment

GPS Aided Navigation & RTK Modules

Construction Tools

Robotics Arms

AMR Navigation with dead reckoning

Navigation

- Applies to GNSS modules, Construction/Agricultural Vehicle, Drone, Mobile Robots
- Gyro and accel measurements used for position and velocity

- **Tilt Sensing**
  - ¬ Applies to Survey, Construction/Agricultural vehicle, Robots, Platform stabilization
  - ¬ Accel measures angles, Gyro important particularly for mobile platforms

IIM-42652 Competitive Comparison

Attracting Tomorrow TDK

Parameters	Units	IIM-42652	ISM330DLC	BMI-055
Manufacturer		**TDK**	**ST**	**Bosch**
Gyro FSR	dps	±250/500/1000/2000	±2000	±250/500/1000/2000
Gyro Noise Density	mdps/√Hz	3.8	12	14
Gyro Offset Over Temp	dps/C	±0.02	±0.015	±0.015
Gyro Sensitivity Scale Factor Variation Over Temp	%/C	±0.005	±0.008	±0.03
Accel FSR	g	±2/4/8/16	±16	±2/4/8/16
Accel Noise Density	ug/√Hz	70	130	150
Accel Offset Over Temp	mg/C	±0.15	±0.11	±1
Accel Sensitivity error Over Temp	%/C	±0.005	±0.012	±0.02
Output data rate (ODR)	Hz	8000	6664	
Size	mm	2.5x3x0.91	2.5x3x0.83	3.0x4.5x0.95
Shock Tolerance	g	20,000 (unpowered) 10,000 (powered)	10,000	10,000
Operating Temp range	C	-40 to 105	-40 to 85	-40 to 85

TDK IIM-42652 advantages over BMI-055

1. More than 4x lower noise density
2. Lower sensitivity variation over temperature
3. Higher operating temperature range
4. Higher shock tolerance
5. Supports wake on motion capability
6. Provides user the ability to provide external clock input
7. Small form factor package: 2.5x3x0.83 mm

TDK IIM-42652 advantages over ST330DLC

1. IIM-42652 provides user the unique ability to provide external clock input enabling improvement of ODR accuracy by ~100x
2. Better Gyro & Accelerator sensitivity over the full temp range
3. Higher operating temperature -40 to 105 C
4. IIM-42652 has much lower noise compared to ST

IIM-42352 - 3-axis Accelerometers

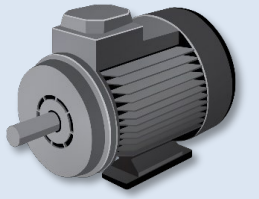
IIM-42352 Accelerometer For Vibration Sensing
Low power, Small form factor

Attracting Tomorrow TDK

Features

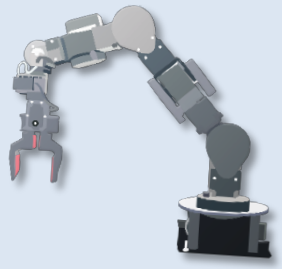
- Digital-output X-, Y-, and Z-axis accel with programmable FSR of ±2g, ±4g, ±8g and ±16g
- Low noise
- External clock input
- Digital-output temperature sensor
- Supports SPI and I²C
- Operating temperature range: -40°C to 105°C
- Small form factor package: 2.5 x 3 x 0.91 mm (14-pin LGA)
- 20,000 g shock tolerant
- MEMS structure hermetically sealed and bonded at wafer level

Parameter	Min	Typ	Max	Unit
ACCELEROMETER				
Full scale Range	±2		±16	*g*
Sensitivity Error Over Temperature	-0.025	±0.005	0.025	%/°C
Zero-G level change vs. Temperature	-0.4	±0.15	0.4	mg/°C
Nonlinearity	-0.2	±0.1	0.2	%
Cross-Axis sensitivity	-2.0	±1	2.0	%
Noise Density		70	100	µg/√Hz
3dB Bandwidth Range		4000		hz
Output Data Rate	1.5625		32000	Hz



Condition Monitoring of Motors and Pumps

Vibration Sensing



Vibration Sensing of Robotic Arms

Advantages

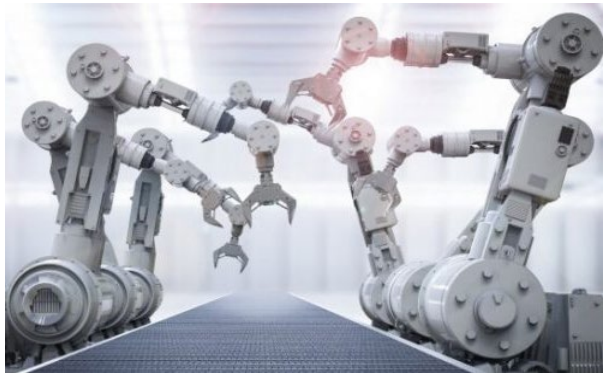
- **Configurable 3 dB Bandwidth – 2 Khz (with ODR = 8 Khz) and 4Khz (with ODR = 16 Khz)**
- **Ability to provide external clock to synchronize with the system**
- **Low power (0.25 mA typical current)**
- **Wake on Motion (WOM) interrupts based on motion detection**

IIM-42352 : Industrial Applications

Attracting Tomorrow TDK

Vibration & Condition Monitoring (CbM)

Motors & Pumps



Robotics Arms

Industry 4.0 – Vibration Monitoring Systems

Vibration Sensing & High Temp Environments -

- Applies to Industrial motors, Robots (servo motor control)
- Conditional base maintenance CBM
- Accelerometer used to measure vibration for machine health monitoring (such as misalignment, bearing fault). The ISO-20816 standard establishes 1Khz vibration measurement needs
- 3dB bandwidth, Low noise and low power

IIM-42352 Competitive Comparison

Parameters	Units	IIM-42352	IIS3DWB	KX-134
Manufacturer		**TDK**	**ST Micro**	**Kionix**
Accel FSR	g	±16	±16	±64
Accel Noise Density	ug/√Hz	70	75	300
Accel Nonlinearity	%			
3dB bandwidth	Hz	4000 (X, Y) 1500 (Z-axis)	6000	8200 (x) 8500 (y) 5600 (z)
Accel Offset Over Temp	mg/C	±0.15	±0.1	±0.5
Accel Sensitivity error Over Temp	%/C	±0.005	±0.01	±0.1
ODR accuracy	% (ppm)	0.005 (50) With external clock	1% (10,000)	
Current (in measurement mode)	mA	0.25	1.1	0.15
Size	mm	2.5x3x0.91	2.5x3x0.83	2 x 2 x 0.9
Shock Tolerance	g	20,000 (unpowered) 10,000 (powered)	10,000	10,000
Operating Temp range	C	-40 to 105	-40 to 105	-40 to 105
Wake on Motion		Yes	Yes	Yes
External clock input		Yes	No	No

TDK IIM-42352 advantages over ST, Kinoix

1. IIM-42352 provides user the unique ability to provide external clock input enabling improvement of ODR accuracy by ~100x
2. IIM-42352 has lower power consumption compared to ST IIS3DWB
3. IIM-42352 has much lower noise compared to KX

Attracting Tomorrow TDK

Parameters	Units	IIM-42352	ADXL355	ADXL326
Manufacturer		**TDK**	**ADI**	**ADI**
Accel FSR	g	±16	±8	±16
Accel Noise Density	ug/√Hz	70	25	300
Accel Nonlinearity	%	0.1	0.3	
3dB bandwidth	Hz	2000 to 4000 (X, Y) 1500 (Z-axis)	1500 (X, Y) <1000 (Z-axis)	1600 (X, Y) <550 (Z-axis)
Accel Offset Over Temp	mg/C	±0.15	±0.15	±1
Accel Sensitivity error Over Temp	%/C	±0.005	±0.01	±0.01
Size	mm	2.5x3x0.91	6 x 6 x 2.1	4 x4 x 1.45
Shock Tolerance	g	20,000	10,000	10,000

TDK IIM-42352 advantages over ADI

1. Lower noise density (326)
2. Lower offset and sensitivity variation over temperature
3. Higher operating temperature range
4. Better frequency response (higher 3dB bandwidth)
5. Higher shock tolerance
6. Supports wake on motion capability
7. Provides user the ability to provide external clock input
8. Small form factor package: 2.4x3x0.91 mm (14-pin LGA)

IIM-42351 - 3-axis Accelerometers

IIM-42351 Accelerometer For Tilt Sensing Low power, Small form factor

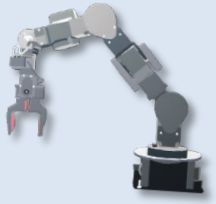
Attracting Tomorrow TDK

Features

- Digital-output X-, Y-, and Z-axis accel with programmable FSR of ±2g, ±4g, ±8g and ±16g
- Low noise
- External clock input
- Digital-output temperature sensor
- Supports SPI and I²C
- Operating temperature range: -40°C to 105°C
- Small form factor package: 2.5 x 3 x 0.91 mm (14-pin LGA)
- 20,000 g shock tolerant
- MEMS structure hermetically sealed and bonded at wafer level

Parameter	Min	Typ	Max	Unit
ACCELEROMETER				
Full scale Range	±2		±16	*g*
Sensitivity Error Over Temperature	-0.025	±0.005	0.025	%/°C
Zero-G level change vs. Temperature	-0.4	±0.15	0.4	mg/°C
Nonlinearity	-0.2	±0.1	0.2	%
Cross-Axis sensitivity	-2.0	±1	2.0	%
Noise Density		70	100	µg/√Hz
Output Data Rate	1.5625		8000	Hz

Tilt Sensing
Inclination of body / arm



Tilt Sensing of Robotic Arms

Digital Levels
Utility poles/wires
Security cameras

Advantages

- Ability to provide external clock to synchronize with the system
- Low power (0.25 mA typical current)
- Wake on Motion (WOM) interrupts based on motion detection

IIM-42351 : Industrial Applications

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Tilt Sensing

Laser Level

Power Tools

Industrial Inclination Sensors

- **Tilt Sensing**
  - ¬ Applies to Survey, Construction/Agricultural vehicle, Robots, Platform stabilization
  - ¬ Accel measures angles, Gyro important particularly for mobile platforms

Optical Level

IIM-42351 Comparison vs NXP MMA8451/ST IISICLX

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TDK IIM-42351 advantages over MMA8451

1. IIM-42351 offers a higher measurement range (FSR)
2. IIM-42351 offers better thermal performance – lower offset and sensitivity variation over temperature
3. IIM-42351 offers higher operating temperature range
4. IIM-42351 offers better frequency response (higher 3dB BW)
5. IIM-42351 supports small form factor package: 2.4x3x0.91 mm (14-pin LGA)

TDK IIM-42351 advantages over IISICLX

1. IIM-42351 offers a more axes (3 vs. 2)
2. IIM-42351 offers a higher measurement range (FSR)
3. IIM-42351 offers better sensitivity thermal performance
4. IIM-42351 offers better frequency response (higher 3dB bandwidth)
5. IIM-42351 supports small form factor package: 2.4x3x0.91 mm (14-pin LGA)

Parameters	Units	IIM-42351	MMA8451	IIS2ICLX
Manufacturer		**TDK**	**NXP**	**ST**
# of Axes		3	3	2
Accel FSR	g	±16	±8	±3
Accel Noise Density	ug/√Hz	70	99 to 126	15
Accel Offset Over Temp	mg/C	±0.15	±0.15	0.08
Accel Sensitivity error Over Temp	%/C	±0.005	±0.008	±0.01
Output Data Rate (ODR)	Hz	8000	800	833
Size	mm	2.5x3x0.91	3 x 3 x 1	5 x 5 x 1.7
Shock Tolerance	g	20,000	N/A	N/A
Operating Temp Range	C	-40 to 105	-40 to 85	-40 to 105

NXP going out of the accelerometer business

The MMA8452, MMA8451, MMA8652, and FXLS8471 have all been discontinued / end-of-life

- - Use the IIM-42351 as replacement

IIM-20670 – Mid Range

IIM-20670 Mid-Range 6-axis IMU High Thermal Stability

Features

- Digital-output X-, Y-, and Z-axis angular rate sensors (gyroscopes) with programmable full-scale range of ±41 to ±1966 °/sec
- Digital-output X-, Y-, and Z-axis accel w/ programmable full-scale range of ±2g to ±64g
- Digital-output temperature sensor
- 10Mhz SPI interface
- 10,000 g shock tolerant
- MEMS structure hermetically sealed and bonded at wafer level

Parameter	Min	Typ	Max	Unit
GYROSCOPE				
Sensitivity Error Over Temperature	-0.5	0.2	+0.5	%
Zero Variation Over Temperature	-0.65	0.25	0.65	dps
Noise Density		5		mdps/√Hz rms
ACCELEROMETER				
Sensitivity Error Over Temperature (X and Y axis)	-0.2	0.1	0.2	%
Zero-G level change vs. Temperature (X and Y axis)	-15	5	15	mg
Noise density (X and Y axis)		172		mg/√Hz rms

Navigation
GNSS/Vision + IMU fusion

Tilt Sensing
Orientation or inclination (6-DoF) of body / arm

Positioning, Stabilization

Advantages

- High thermal stability
  - ¬ Low offset and sensitivity drift over temperature
- Operating temperature range: -40°C to 105°C
- Good performance in presence of vibration
- Small form factor package: 4.5 x 4.5 x 1.1 mm (24-pin DQFN)

IIM-20670 : Industrial Applications

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Motion

GPS / GNSS Modules

Agricultural RTK Modules

Industrial Inclination Sensors

- **RTK & GNSS modules**
  - ¬ Applies to survey equipment & good performing inertial navigations

IIM-20670 Competitive comparison against ADXRS620

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TDK IIM-20670 advantages over ADXRS620

1. IIM-20670 is 6 axis motion sensor which combines 3-axis Gyroscope and 3-axis accelerometer. ADXRS620 support only single axis
2. IIM-20670 gyroscope supports programmable full-scale range of from ±41 to ±1966 degrees/sec, while ADXSR620 is limited to ±300 degrees/sec
3. IIM-20670 offers better performance – lower bias instability, ARW and noise density
4. IIM-20670 offers better thermal performance – lower offset and sensitivity variation over temperature
5. IIM-20670 supports small form factor package: 4.5x4.5x1.1 mm (24-pin DQFN)
6. IIM-20670 is10,000 *g* shock tolerant, while ADXRS620 is only 2000g shock tolerant

Parameters	Units	IIM-20670	ADXRS620
Manufacturer		**TDK**	**ADI**
Gyro FSR	dps	±1966	±400
Gyro Noise Density	mdps/√Hz	5.4	3.8
Gyro Bias instability	dph	13	21.6
Angular random walk	deg/√hr	0.23	0.31
Gyro Offset Over Temp	dps	±0.6 (max)	±5 (typ)
Gyro Sensitivity error Over Temp	%	±0.6 (max)	±2 (typ)
Size	mm	4.5 x 4.5 x 1.1	7 x 7 x 3
Shock Tolerance	g	10,000	2000
Operating Temp range	C	-40 to 105	-40 to 105

IIM-4623X – High Performance

High Performance Industrial IMU Family

Accel Gyro Temp

6-axis Motion sensing module (Gyroscope + Accelerometer) that enables easy, robust and accurate inertial measurements in Industrial applications:
*More info at **Invensense.com/industrial***

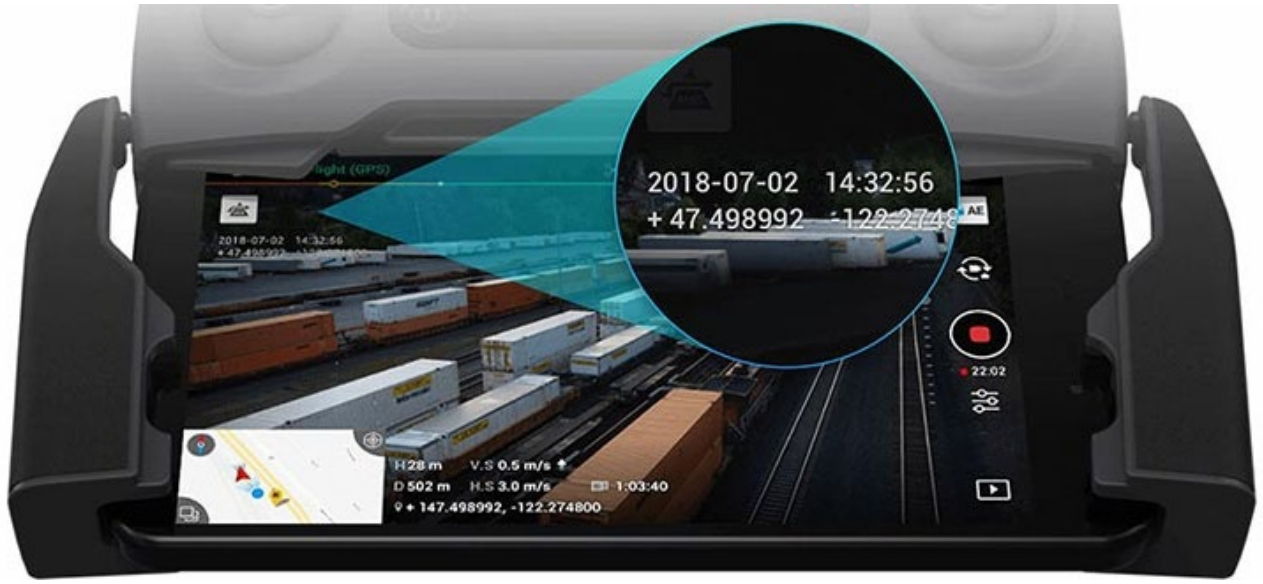
Fault Tolerant

Hardware Backup

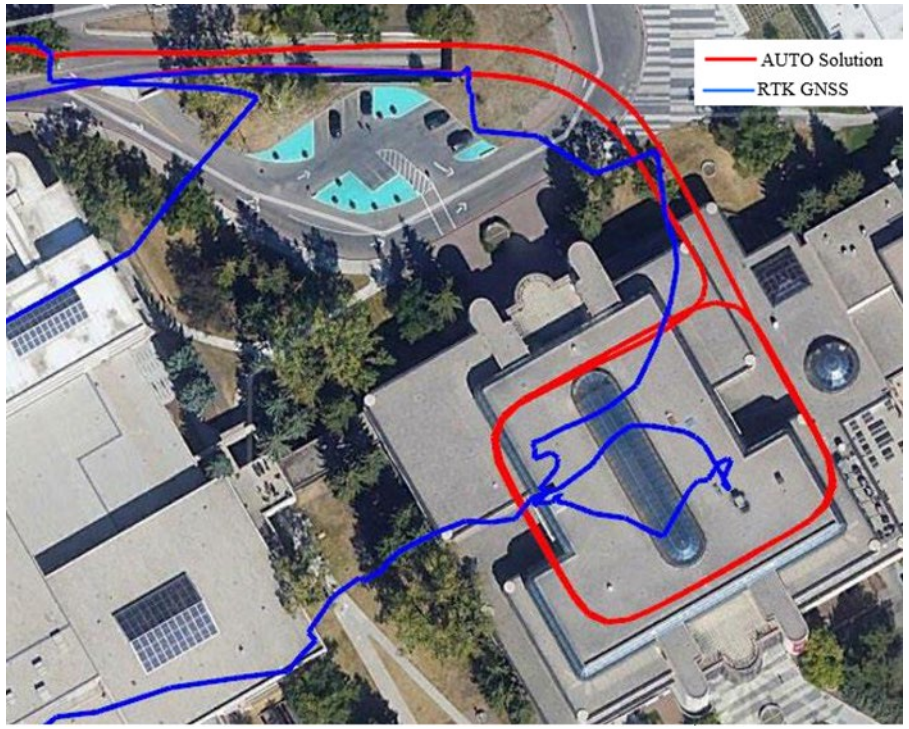
- The SensorFT™ feature uses TDK proprietary fault detection and recovery algorithm to deliver redundancy
- Automatically tries to recover when it detects performance degradation.

Early warning

Time Stamping



AUTO – Performance with IIM-46234



Outage Details			Error in Position		Error in Heading
Outage Duration (s)	Travelled Distance (m)	Average Speed (km/h)	RMS Error (m)	RMS %	RMS Error (Deg)
10	152.8	49.93	0.49	0.32%	0.16
20	276.4	47.27	0.85	0.31%	0.22
30	388.8	45.06	1.06	0.27%	0.20
60	681.0	40.06	1.90	0.28%	0.28
120	1452.9	43.09	3.19	0.22%	0.30

IIM-46234 and IIM-46230: High Performance Module

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Parameter	Value	Unit
GYROSCOPES		
Dynamic Range	±480	°/sec
Sensitivity Error Over Temperature	±0.2	%
Misalignment	0.1	Degrees
Bias		
In-Run Stability	1.9	°/hr
Angular Random Walk	0.09	°/√hr
Noise		
Noise Density	1.6	mdps/√Hz rms

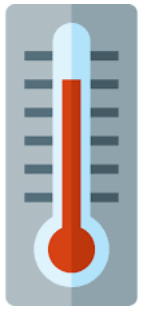
Parameter	Value	Unit
ACCELEROMETERS		
Dynamic Range	±8	*g*
Sensitivity Error Over Temperature	±0.2	%
Misalignment	0.1	Degrees
Bias		
In-Run Stability	7.0	µg
Velocity Random Walk	0.013	m/sec/√hr
Noise		
Noise Density	30.6	µg/√Hz rms

Parameter	Value	Unit
GYROSCOPES		
Sensitivity Error Over Temperature	±0.3	%
Misalignment	0.1	Degrees
Bias		
In-Run Stability	4.1	°/hr
Angular Random Walk	0.15	°/√hr
Noise		
Noise Density	3.4	mdps/√Hz rms

Parameter	Value	Unit
ACCELEROMETERS		
Sensitivity Error Over Temperature	±0.3	%
Misalignment	0.1	Degrees
Bias		
In-Run Stability	9.9	µg
Velocity Random Walk	0.02	m/sec/√hr
Noise		
Noise Density	43	µg/√Hz rms

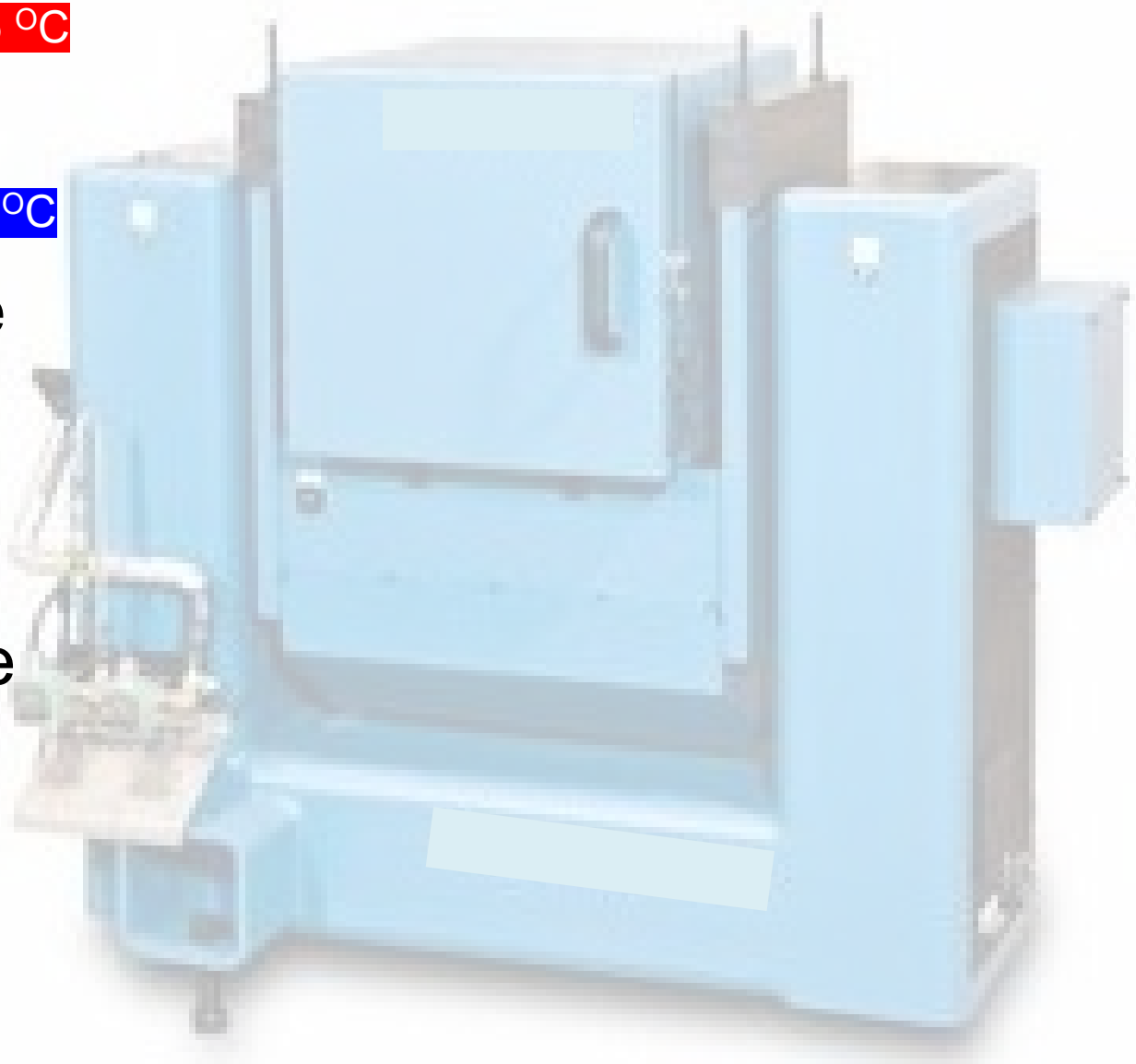
IIM-4623X Calibration & Final Test(FT)

- Temperature Calibration



- Sensor trimmed over temperature
  - ✓ Accelerometer range +/-1 g
  - ✓ Gyroscope range ± 460 °/s

- Calibration & FT over temperature
  - ✓ Bias
  - ✓ Sensitivity
  - ✓ Cross-axis
  - ✓ G-Sensitivity



IIM-4623X : Industrial Applications – High End Navigation

Attracting Tomorrow

High end Modules

IIM-4623x delivers similar or better level of Performance as other high performance Industrial IMUs, & offers unique Fault Tolerance, Timestamping Features at a competitive cost

VS

ANALOG DEVICES

- ✓ Gyro Noise Density – 1.6 mdps/√Hz
- ✓ Bias Instability – 1.9 dps
- ✓ ARW – 0.09 deg/√hr
- ✓ Sensitivity Error Over Temperature – ±0.2 %

EPSON®

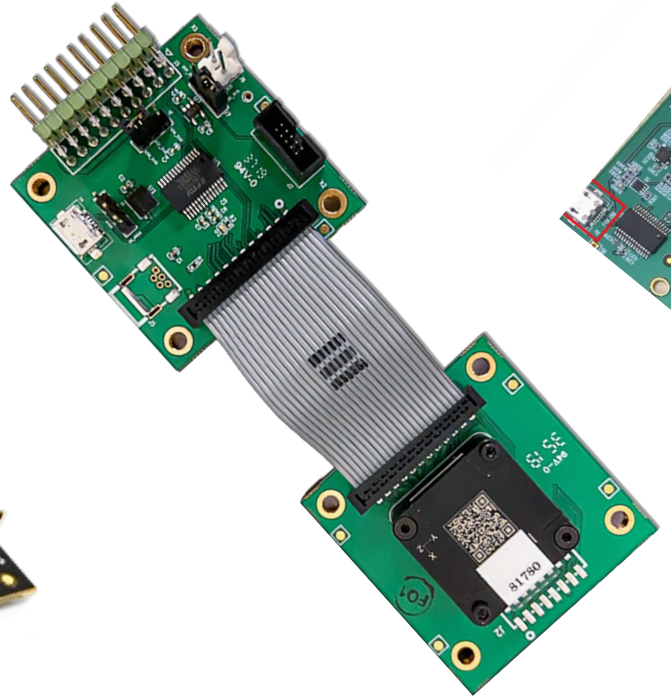
- ✓ Fault Tolerance*
- ✓ Time Stamping*

Industrial IMUs Summary

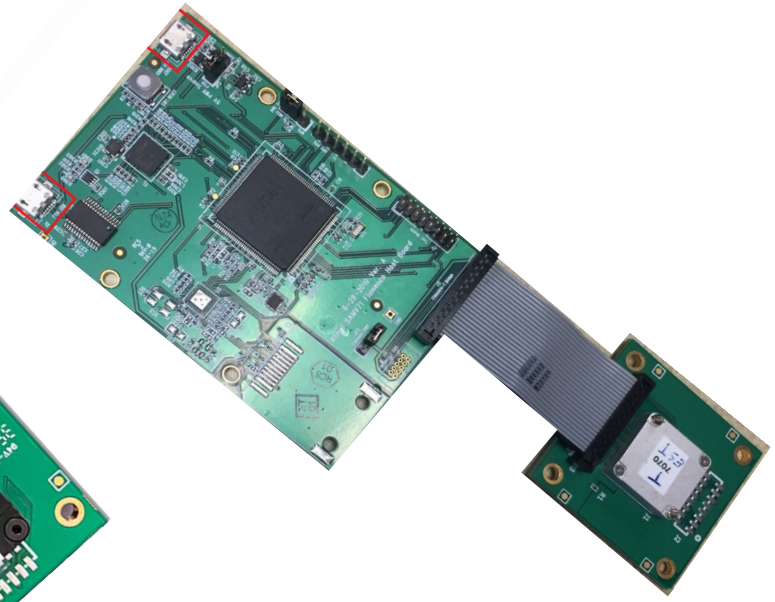
Family	Parts	Description	Competition
High performance IMU modules	IIM-46234	Fault tolerant, High accuracy, low noise Factory calibrated for high thermal stability	ADI
	IIM-46230		
Mid-range IMU devices	IIM-20670	High thermal stability, Extended temp (-40 to 105C)	ADI, Murata
Compact IMUs	IIM-42652	Low power, small form factor, Extended temp (-40 to 105C)	ST, Bosch
3-axis Accelerometer (vibration sensing)	IIM-42352	Low noise, 4Khz bandwidth range, Extended temp (-40 to 105C)	ADI
3-axis Accelerometer (Tilt sensing)	IIM-42351	Low power, small form factor, Extended temp (-40 to 105C)	NXP/ST

Development Products

DK board



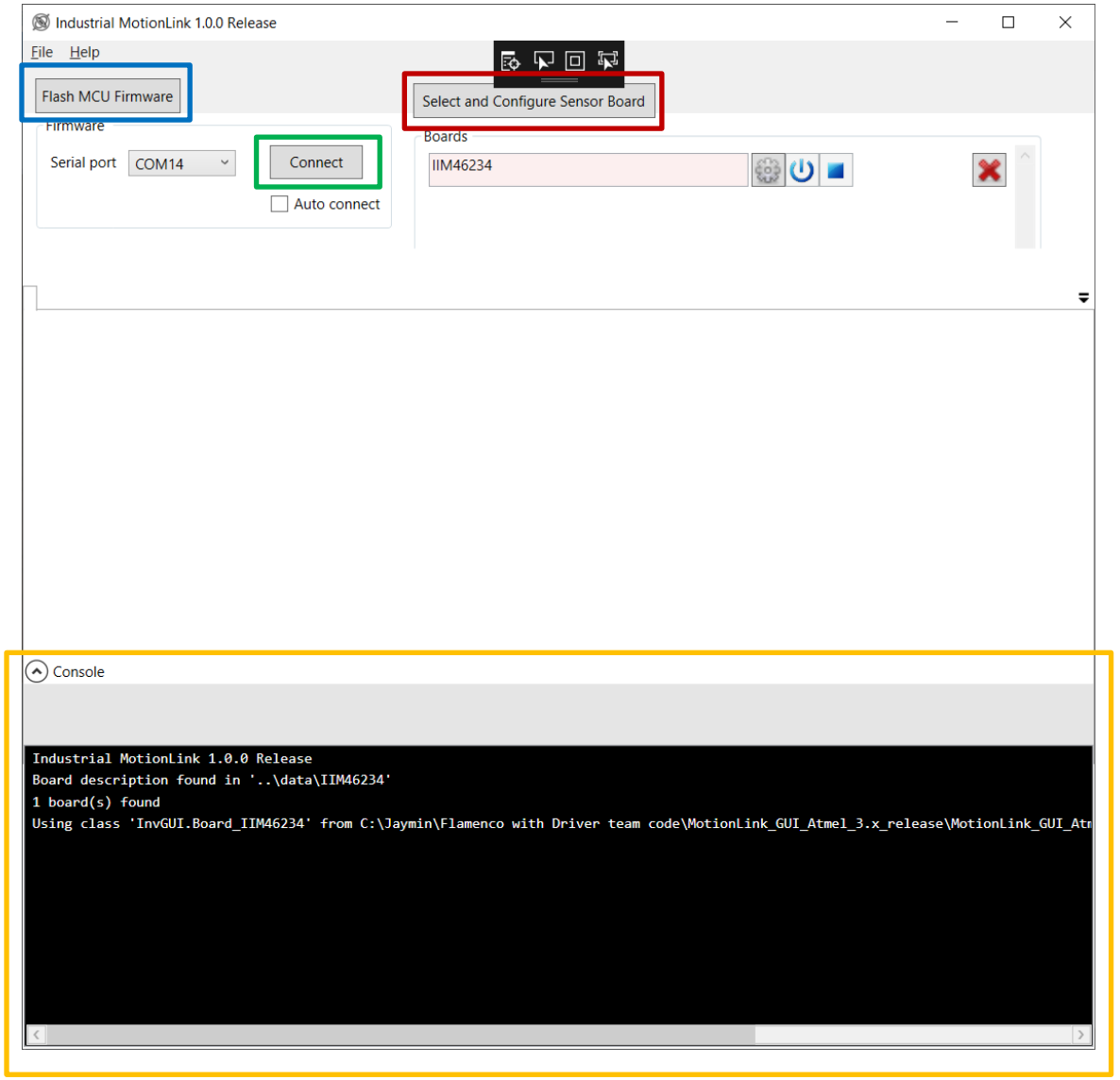
EVB board



DK board

Motion Link Application GUI

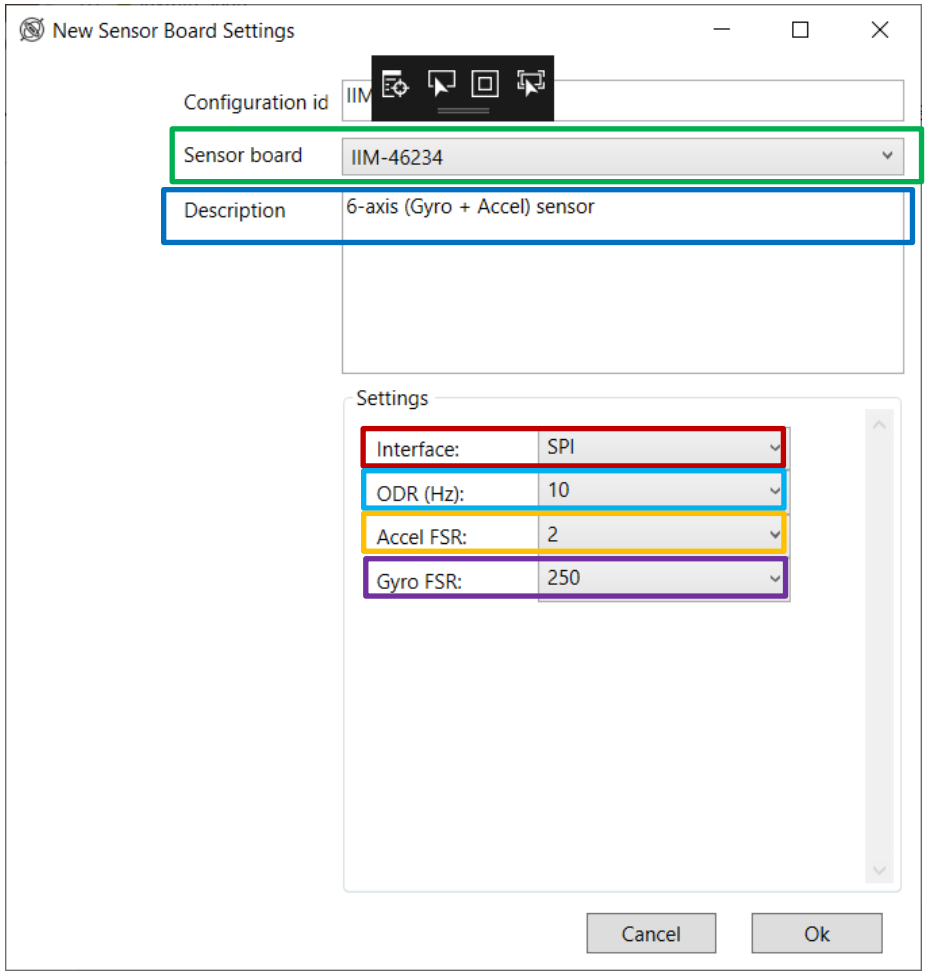
1) Connect button will establish communication between the application and host board on Serial port via UART.
2) Flash MCU firmware can be used to upgrade host board firmware
3) Select and Configure Sensor Board will be used to configure sensor.(on next slide)
4) Console output screen with status messages



Legends: Completed On-track Delayed issues

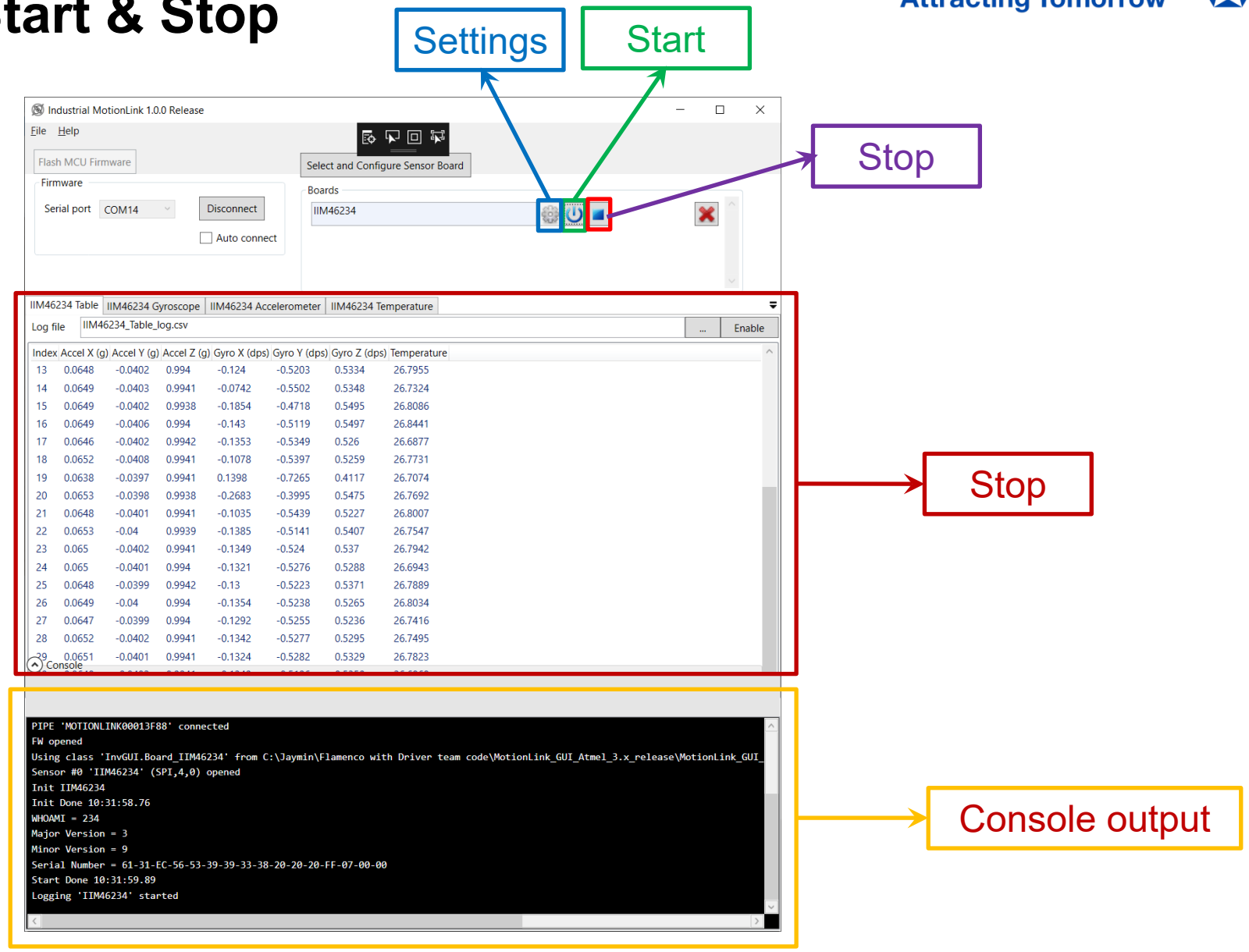
Select & Configure Sensors

1) Sensor Board is dropped down menu to select sensor.
2) Description is about sensor.
3) Interface can be selected to SPI or UART.
4) ODR is sensor output rate.
5) Accel FSR is accelerometer full scale range.
6) Gyro FSR is gyroscope full scale range.

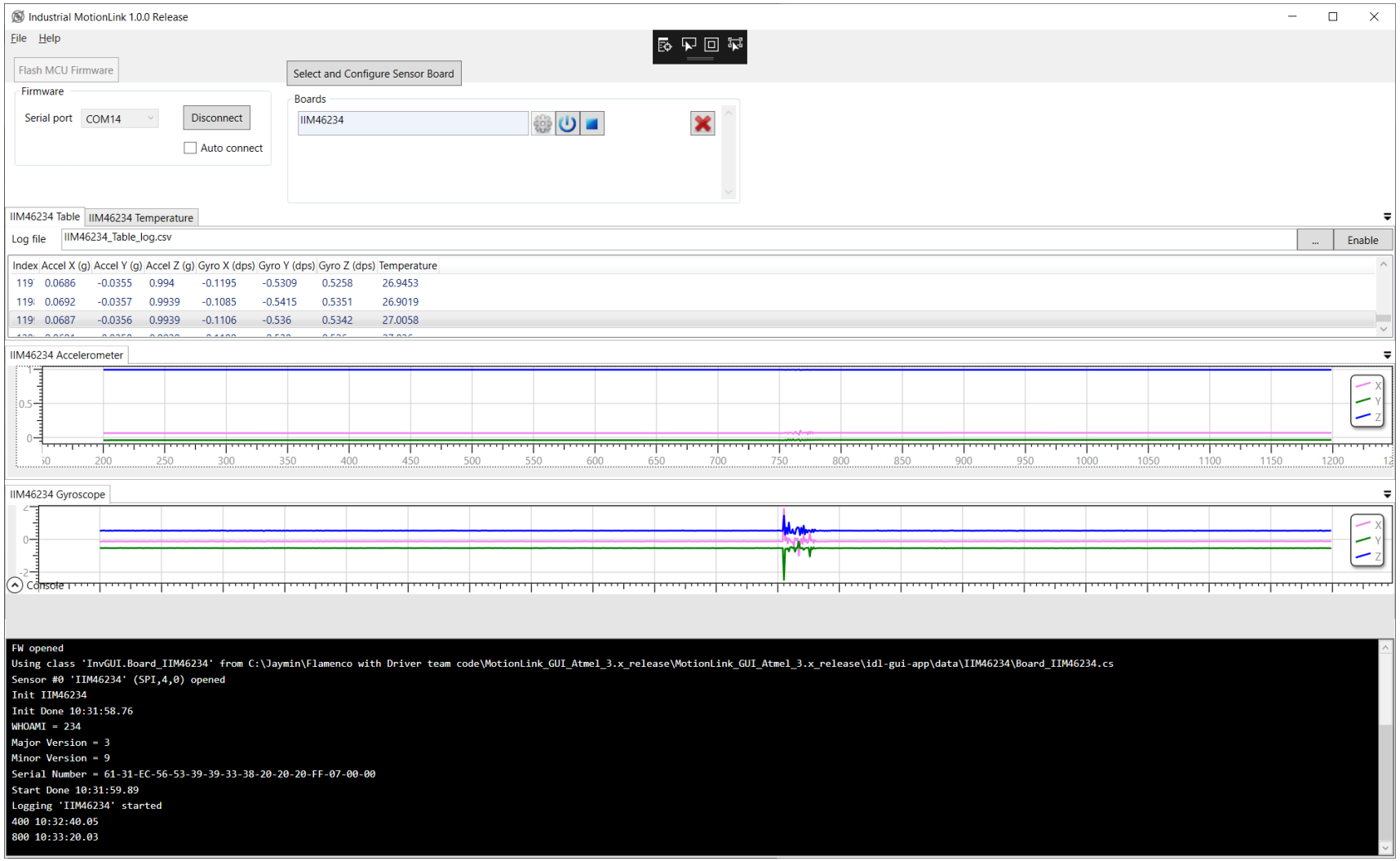


Legends: Completed On-track Delayed issues

Data Streaming Start & Stop



Streaming Data Visualization



Data Start & Stop

Data Table

Data Visualization

Console Output

Thank You!

For additional resources, and to download a copy of this presentation, please scan the QR code to the right.