Attracting Tomorrow

Motion Sensors Technology & Applications from TDK-InvenSense

April 2019

InvenSense
MEMS Sensor Group
Sensor System Business Company
04/11/2019

Agenda

- **Introduction to TDK-InvenSense Motion Technology**
  - ¬ Basics of Motion Technology
  - ¬ Motion Sensor Product Portfolio
  - ¬ Applications of Motion Sensing
- **Product Offerings**
  - ¬ Specifications, Applications, Solution Benefits
  - ¬ Success Stories
- **SmartMotion Evaluation Kits**
  - ¬ Quick introduction to SmartMotion
  - ¬ Evaluating Corona with MotionLink
  - ¬ The DK-42605
- **Wrap up**
  - ¬ Important Links to Support and further Information

Presenter

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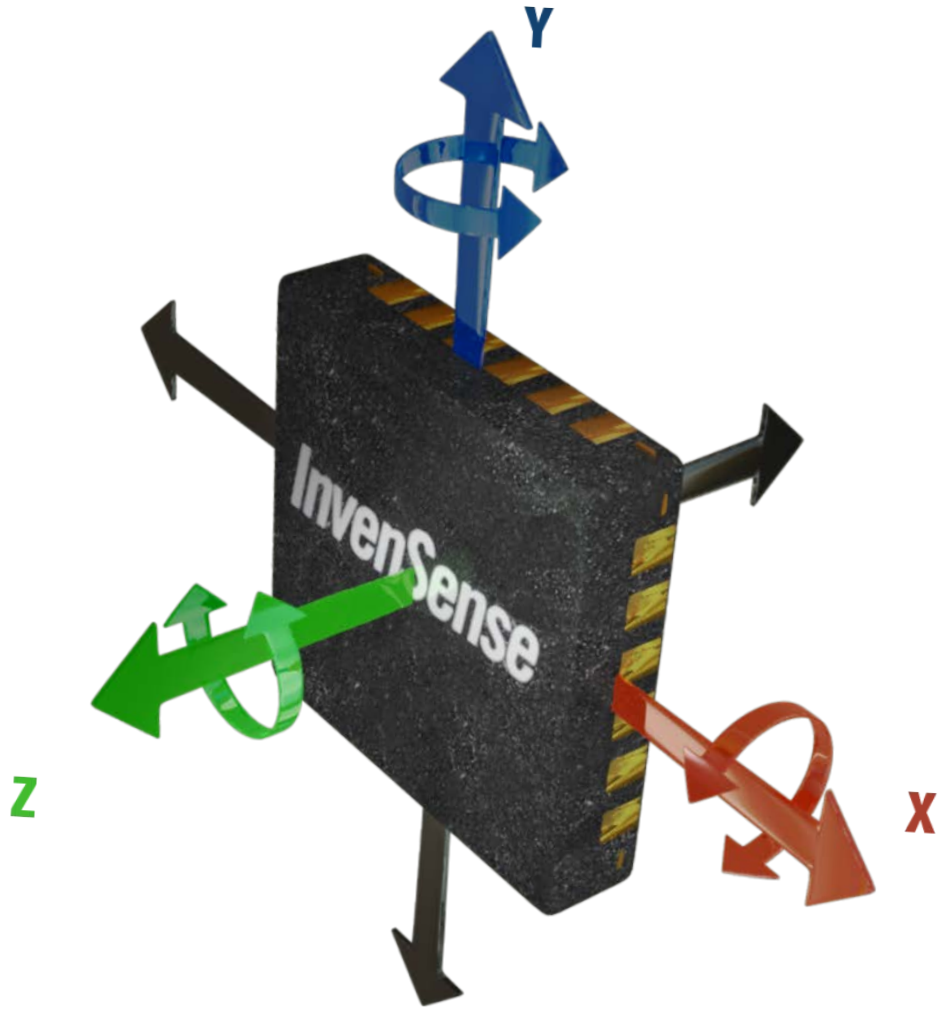
Target Applications

Internet of
Sensors

What is Motion?

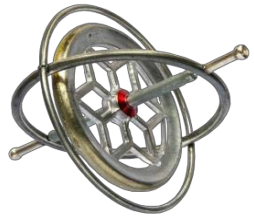
- Motion is change in position of an object over time
- Any motion in 3D space is a combination of rotation and translation along X, Y, Z axes
- Gyroscopes and Accelerometers used for Motion Sensing



Sensors Summary

Gyroscope

- Measures rate of angular rotation (dps)
- Gyroscope full scale range typically goes up to ±2000dps



Accelerometer

- Measure acceleration or change in linear velocity
- Measured in g or in m/s^2 (1g = 9.81 m/s^2)
- Accelerometer full scale range typically goes up to ±16g

Compass

- Measures magnetic fields
- Used to provide “heading” or direction information

Pressure Sensor

- Measures atmospheric air pressure
- Used to provide altitude change information

Gyroscopes & Accelerometers – Critical Device Specs

- **Offset**
  - The gyro output for zero rate input rotation (device not moving) and the accel output value for zero-g input acceleration at nominal Vdd and temperature.

- **Full-Scale Range**
  - This parameter defines the measurement range of the gyroscope in degrees per second (dps) and accelerometer in (g).
  - When the applied angular velocity and the applied linear acceleration is beyond the full-scale range, the gyroscope and accel output signal will be saturated.

- **Sensitivity**
  - Gyroscope: The output change per unit of input rotation at nominal Vdd and temperature, measured in LSB/deg/sec.
  - Accelerometer: The output change per unit of input acceleration at nominal Vdd and temperature, measured in LSB/g.

- **Offset / Sensitivity vs. Temperature**
  - The maximum change in the gyro and accel offset/sensitivity over the full operating temperature range (Typically -40 deg C to +85 deg C).
  - The closer to zero and the more linear, the better.

- **Noise Density**
  - When multiplied by the square root of the measurement bandwidth, this value will give the RMS noise of the sensor at nominal Vdd and temperature.
  - Rotations and accelerations below this value will not be resolvable.

Motion Sensor Product Portfolio

	Current Channel Products	Upcoming Corona XLII Offerings
Motion, Pressure & Combo Sensors		

ICM-20648
- **6-axis (w/sensor fusion)**
- 3x3x0.9mm
- in MP
- IoT/Wearables

ICM-20948
- **9-axis (w/compass)**
- 3x3x1mm
- in MP
- Navigation, IoT

ICM-20690
- **Dual-Interface: 6-axis UI+OIS**
- 2.5x3x0.9mm
- in MP
- Smartphones, Imaging

ICM-20602
- **Single-Interface: 6-axis UI**
- 3x3x0.75mm
- in MP
- VR/Game controllers

ICM-20789
- **7-axis (w/pressure sensor)**
- 4x4x1.365mm
- in MP
- Wearables, Drones, IoT

ICM-20600
- **Single-Interface: 6-axis UI**
- 2.5x3x0.91mm
- in MP
- Smartphones

ICP-101xy
- **1-Axis pressure**
- 2x2x0.72mm
- in MP
- Smartphones, Drones, IoT

ICM-42605
- *Next Gen 6-Axis Flagship*
- Further improved Gyro/Accel performance
- I3C Support
- APEX Motion Engine
- 2.5x3x0.9mm
- MP: 2Q 2019

ICM-42686
- *Highest range* Gyro/Accel
- Further improved Gyro/Accel performance
- 18-bits(Accel),19-bits (Gyro) output option
- I3C Support
- APEX Motion Engine
- 2.5x3x0.9mm
- MP: 2Q 2019

ICM-42688
- *Highest precision* Gyro/Accel
- Further improved Gyro/Accel performance
- 18-bits(Accel),19-bits (Gyro) output option
- I3C Support
- APEX Motion Engine
- RTC Input
- 2.5x3x0.9mm
- MP: 2Q 2019

Sports

- Swing Analysis:
  - ¬ Golf, baseball, tennis, cricket etc.
  - ¬ 6-axis motion sensor embedded in golf club, bat
  - ¬ Motion sensor tracks player's swing and sends data to computer/smartphone application
  - ¬ Application analyzes player's swing and provides feedback for improvement

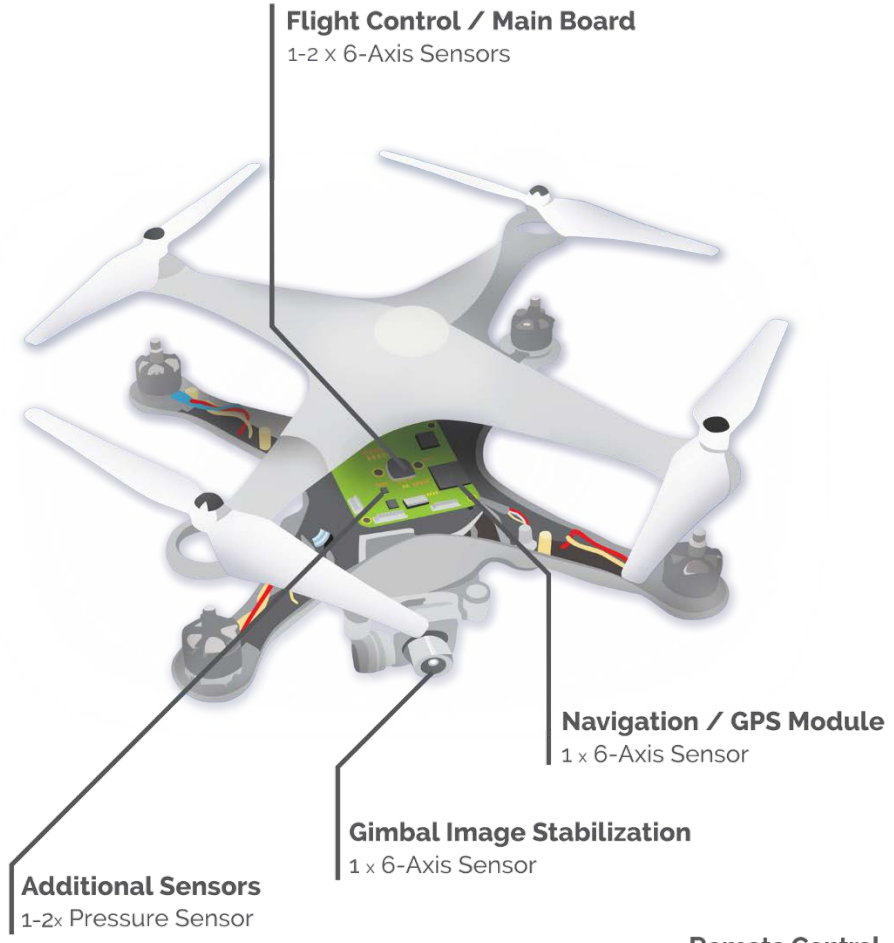
- Other sports examples:
  - ¬ Ski motion analysis
  - ¬ Motion sensor in soccer ball to track ball motion during game
  - ¬ Biking: Wheel mounted motion sensor monitors applied forces – used to control suspension system
  - ¬ Archery: Arrow mounted motion sensor measures arrow's flight characteristics and impact ballistics data

TDK-InvenSense Solution: ICM-20649/ICM-42686 for industry leading accuracy

Drones

- Vertical stabilization camera takes an image of the ground every 16 milliseconds and compares it to the previous one to determine the speed of the drone
- Ultrasound sensor analyzes the flight altitude up to 16 feet
- Pressure sensor measures air pressure and analyzes fight altitude beyond 16 feet
- 3-axis gyroscope measures the bank angle of the drone
- 3-axis accelerometer measures the positioning of the drone on 3 axes and its linear speed
- 3-axis magnetometer helps define the position of the drone
- Microphone captures audio as part of media recording
- Global Navigation Satellite System (GNSS) chipset (GPS + GLONASS) geo-localize the drone and help measure the speed in order to stabilize the drone in high altitudes
- Drone controller with gyroscope + accelerometer; microphone to record commentary

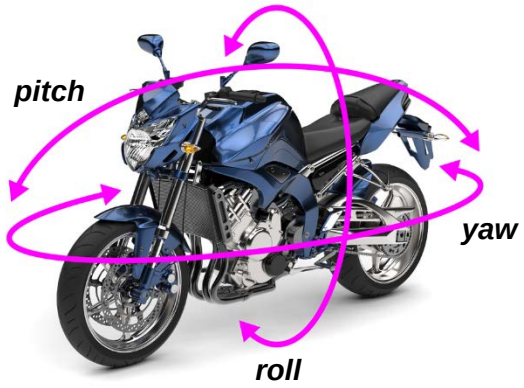
* *Items in blue are sensors provided by TDK-InvenSense*

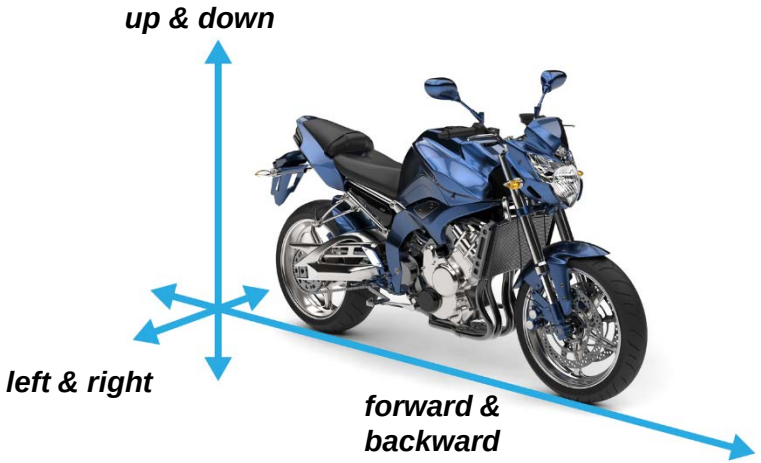


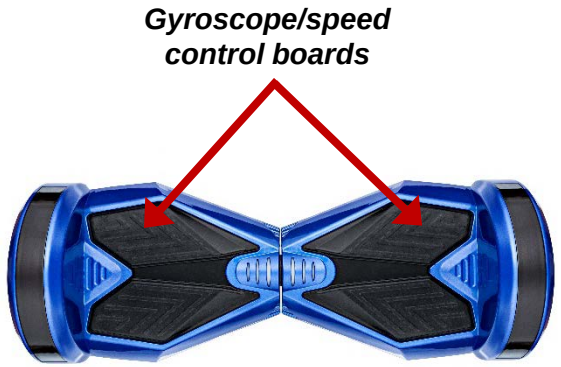
TDK-InvenSense Solution: ICM-20789 6-axis + pressure sensor

e-Scooters, Bikes, Hoverboards

- 6-axis motion sensor measures
  - ¬ Acceleration in the forward-backward, up-down and right-left directions
  - ¬ Angular velocity in the vehicle's pitch, roll and yaw directions
  - ¬ Calculates and relays position information in real-time to the bike's systems to control the engine and chassis behavior to assist the rider
- Safety: Shuts off engine on fall detection
  - ¬ Minimizes rider drag/injury
- Hoverboard: Motion sensor used to control balance and speed







TDK-InvenSense Solution: ICM-20648 6-axis w/DMP for real time motion processing

Tools (Screwdrivers, Drills etc.)

- Motion sensor in tool senses the motion of user wrist
  - ¬ Changes direction and speed to help user tackle projects with ease
- Safety: Shuts off if tool jams in a hole
  - ¬ Normally, such an occurrence would twist the tool, and user wrists and arms.
  - ¬ Motion sensor detects when the drill is suddenly overburdened and turns off the motor

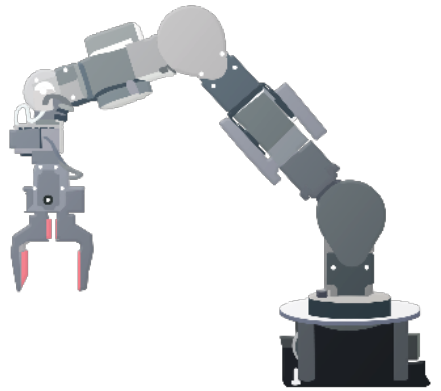
TDK-InvenSense Solution: ICM-42688 for industry leading accuracy

Automotive

- Airbags – Accelerometer used for crash sensing
- Automatic Headlight Leveling – Accelerometer used for tilt sensor
- GPS – Gyro sensor
- Stability Control – Gyro plus accelerometer sensor sense yaw, and compensate for over and under steering on a slick road surface.
- Tire Pressure Monitoring Systems – Pressure, temperature, and accelerometers assure that tires are properly inflated, come standard on all 2008 model year cars sold in the US.
- Manifold Absolute Pressure (MAP) Sensor – Pressure sensor used for engine control
- Seat cushion air bladder – Pressure sensor used for inflating and deflating the bladder.
- Seat belt pre-tensioner system – Pressure sensor used to lock seat belt during a crash

Industrial

- Antenna and Platform Stabilization
- Precision Agriculture
- Precision Robotics
- Land/Aire/Sea Navigation
- Unmanned Systems Control
- Tracking First Responders



HMD & AR/VR

HMD & AR/VR

HMD & Controller

Mobile AR/VR Gaming

- HMD & Controller require different capabilities from motion sensors

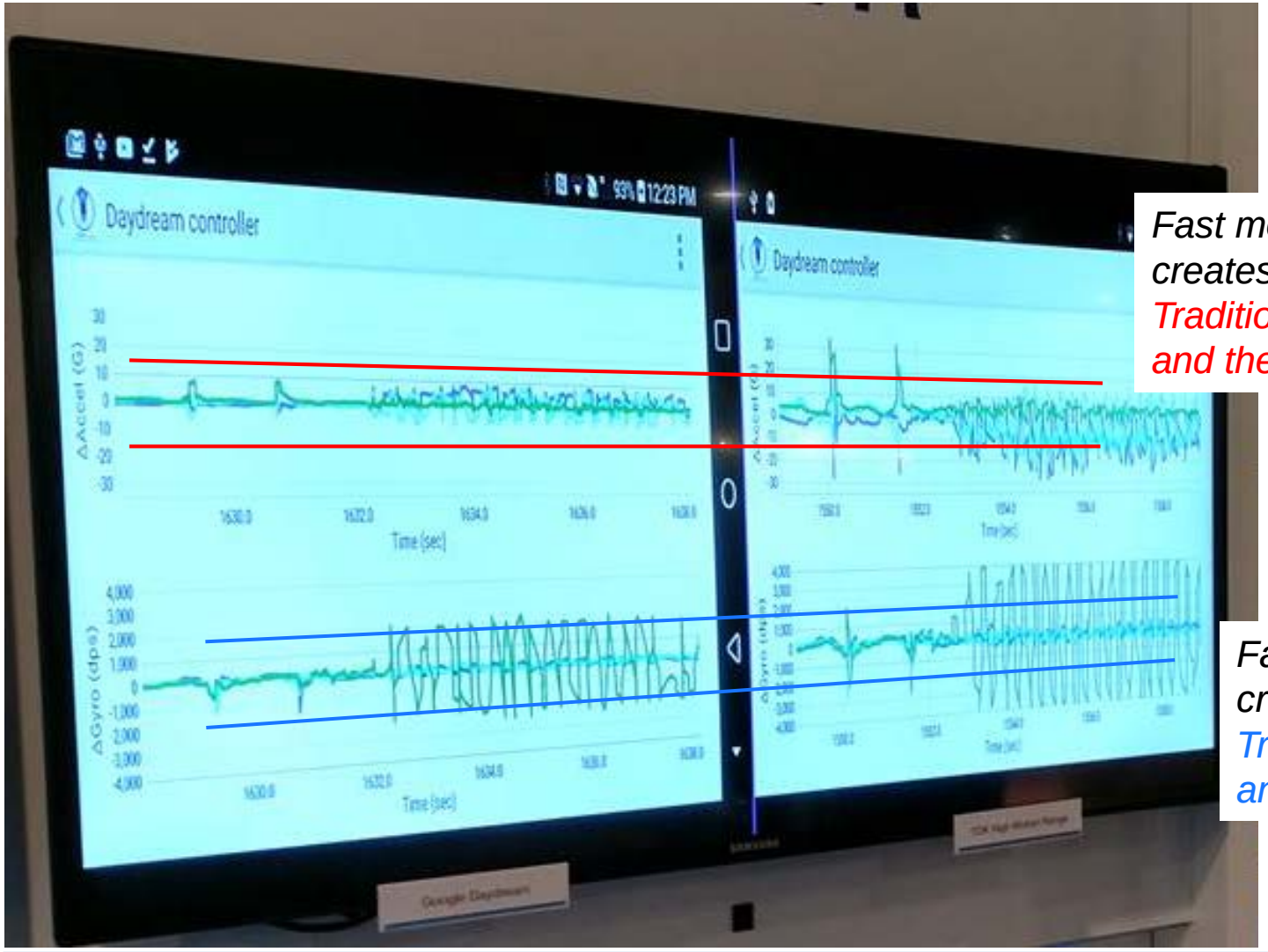
- Controller requires fast motion detection (high FSR such as ±4000dps) for high speed games
- **User Experience:** If motion sensor in controller cannot handle fast motion, it may result impact game experience

- HMD requires accurate sensing of subtle head movement
- **User Experience:** Accurate motion sensing results in HMD presentation being well aligned with user movements

- Mobile gets hot because GPS, AP/Graphics, Display on 100%
- Stable gyroscope performance over temperature is critical
- **User Experience:** Objects won't drift over camera scene as temperature increases

CORONA ICM-42686: Designed for VR Controllers

ICM-42686 High FSR for VR Controllers: ±4000dps; ±32g



Fast movement easily creates acceleration >16g
Traditional 6-axis saturate and the game is over

Fast movement easily creates rotation >2000dps
Traditional 6-axis saturate and the game is over

Navigation

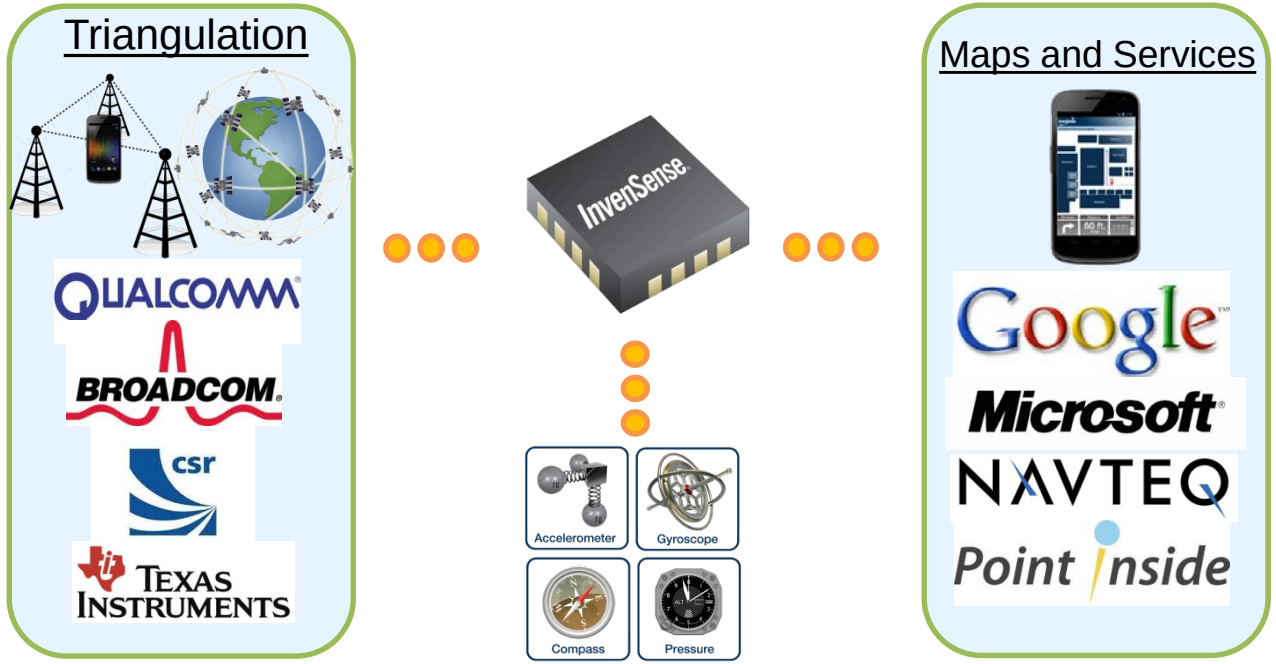
Navigation

Outdoor Navigation:

- GPS + Compass is common (<10m accuracy)
- Motion Sensors help when GPS is lost

Indoor Navigation:

- No GPS, WiFi triangulation for 10-30m accuracy
- Motion Sensors provide 1-10 meter accuracy
- Pressure Sensor: Which floor?



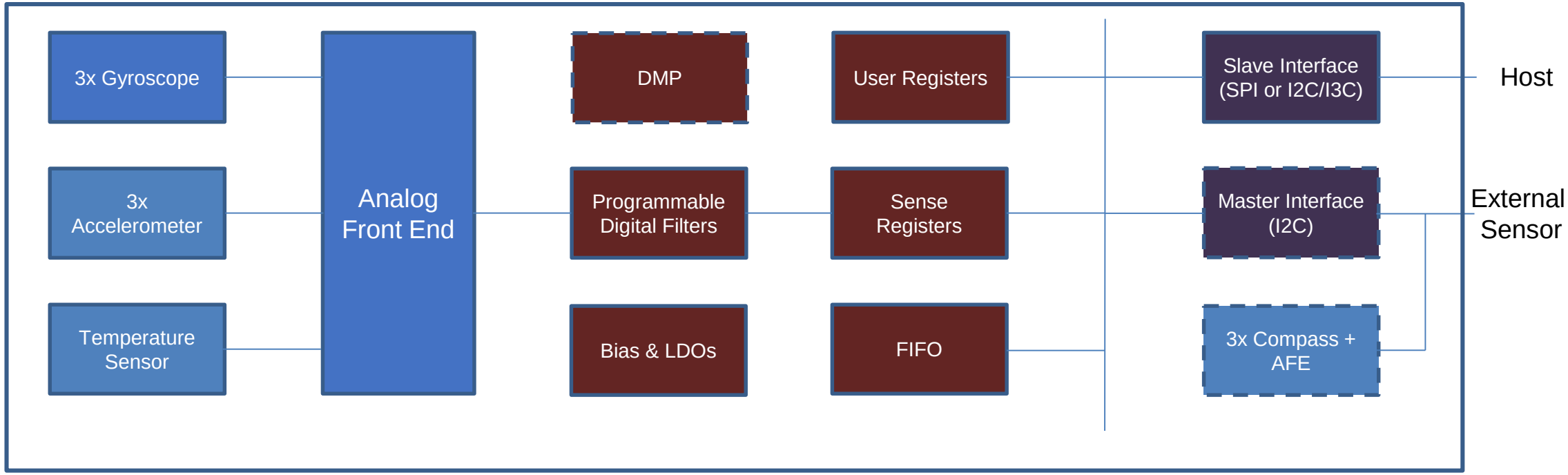
Navigation Errors from Sensor Specs

- Relative contributions from various Sensor Specs to Navigation Errors
- Accel and Gyro Offset are biggest error contributors in this example
  - Important to compensate for offset in system

Sensor Spec	Example Spec Value	Velocity Error	Position Error
Accel Offset	20mg	1.96m/s	9.8m
Accel Sensitivity	0.5%	0.49m/s	2.45m
Accel Noise	0.7mg-rms	0.069m/s	0.34m
Gyro Offset	0.5dps	4.28m/s	14.3m
Gyro Sensitivity	0.5%	2.6m/s	8.6m
Gyro Noise	0.038dps-rms	0.32m/s	1.08m

Product Offerings

Motion Sensor Device



- Digital Filters: Programmable characteristics (bandwidth, noise, latency); Filters for Low Noise and Low Power Modes
- User Registers: User configuration parameters (device modes, FSR, ODR, filter selections); Interrupts status
- FIFO to store data for sending to Host in bursts – helps reduce system power by reducing frequency of host wakeup
- Slave Interface to Host: SPI or I2C
- Master Interface (I2C) for interfacing to external sensors. Bring data from external sensors on chip for fusion with on-chip data
- DMP: On-chip motion processor offloads motion processing from host

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ICM-42688
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- 18-bits(Accel),19-bits (Gyro) output option
- I3C Support
- APEX Motion Engine
- RTC Input
- 2.5x3x0.9mm
- MP: 2Q 2019

ICM-42605

Next Generation 6-axis Solution

Samples: Now
Production: 2Q 2019

Specifications

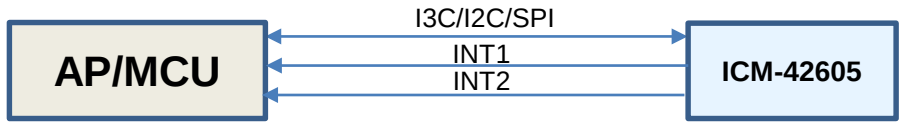
- High Performance Gyro
  - Gyro Sensitivity Error: ±0.5%
  - Gyroscope Noise: ±3.8mdps/√Hz
- High Performance Accel
  - Accel Noise: ±70µg/√Hz
  - Accel Sensitivity: ± 0.5%
- Low Power Solution
  - Full Power: 0.65mA
  - LP Accel Mode: 46µA
- Gyroscope Full-Scale Range: ±250/500/1000/2000 deg/sec
- Accelerometer Full-Scale Range: ±2/4/8/16g
- Package Size: 2.5x3x0.91mm 14-Pin LGA
- Software Available: Yes

Applications

- IoT
- Augmented Reality
- Drone
- Virtual Reality

Solution Benefits

- Device includes 2K-byte FIFO to reduce traffic on serial bus interface
- Reduce power consumption by allowing the system processor to burst read sensor data and then go to LP mode
- Includes on chip, 16-bit ADC's, programmable digital filters, an embedded temp sensor, and programmable interrupts.



ICM-20602

High Performance 6-axis Solution

Samples: Now
Production: Now

Specifications

- High Performance Gyro
  - Gyro Sensitivity Error: ±1%
  - Gyroscope Noise: ±4mdps/√Hz
- High Performance Accel
  - Accel Noise: ±100µg/√Hz
  - Accel Sensitivity: ± 1%
- Low Power Solution
  - Full Power: 2.79mA
  - LP Gyro/Accel Mode: 1.33mA
- Gyroscope Full-Scale Range: ±250/500/1000/2000 deg/sec
- Accelerometer Full-Scale Range: ±2/4/8/16g
- Package Size: 3x3x0.75mm 16-Pin LGA
- Software Available: Yes

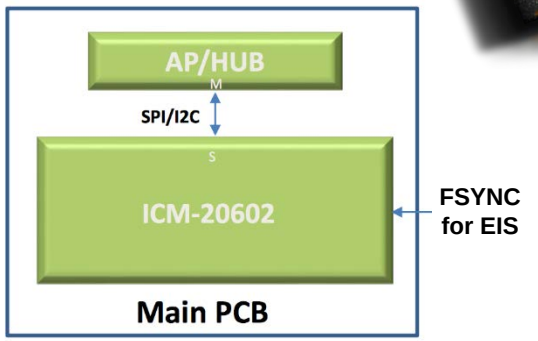
Datasheet: ICM-20602 DataSheet

Applications

- IoT
- Augmented Reality
- Drone
- Virtual Reality

Solution Benefits

- Device includes 1K-byte FIFO to reduce traffic on serial bus interface
- Reduce power consumption by allowing the system processor to burst read sensor data and then go to LP mode
- Includes on chip, 16-bit ADC's, programmable digital filters, an embedded temp sensor, and programmable interrupts.



ICM-20648

6-Axis DMP Enabled Solution

Samples: Now
Production: Now

Specifications

- Digital Motion Processor (DMP) for autonomous operation
- Programmable interrupts, filters, and 4k-byte FIFO
- Gyroscope Full-Scale Range: ±250/500/1000/2000 deg/sec
- Accelerometer Full-Scale Range: ±2/4/8/16g
- Runtime Calibration
- Operating Temperature Range: -40ºC to 85ºC
- Operating Voltage Range:
  - VDD 1.71V – 3.6V
  - VDDIO: 1.71V – 3.6V
- Host Interface: SPI 7MHz, I^2C up to 400kHz
- Package Size: 3x3x0.9mm 24-Pin QFN
- Software Available: Yes

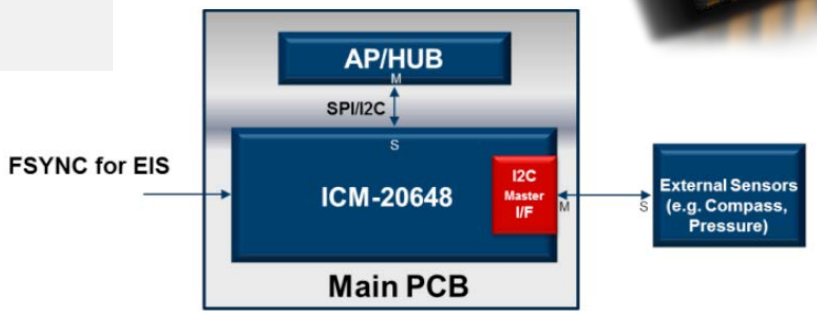
Datasheet: ICM-20648 DataSheet

Applications

- IoT
- EIS
- Wearables

Solution Benefits

- Provides Step Count, Activity Classifier, and B2S (Bring-to-See) Gestures tuned for wrist worn wearable applications.
- DMP offloads computation of motion processing algorithms from the host processor, improving system power performance
- Enhanced FSYNC functionality to improve timing for applications like EIS



ICM-20948

World's Best 9-Axis Integrated Solution

Samples: Now
Production: Now

Specifications

- Digital Motion Processor (DMP) for autonomous operation
- Gyroscope Full-Scale Range: ±250/500/1000/2000 deg/sec
- Accelerometer Full-Scale Range: ±2/4/8/16g
- Operating Voltage Range:
  - VDD 1.71V – 3.6V
  - VDDIO: 1.71V – 1.95V
- Host Interface: SPI 7MHz, I^2C up to 400kHz
- Software Available: Yes
- Low Power Mode: 2.5mW
- Compass FSR: ± 4900µT
- Package Size: 3x3x1mm 24-Pin QFN
- Software Available: Yes

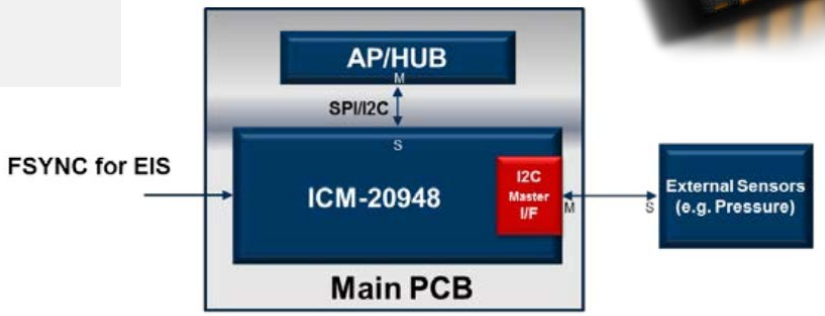
Datasheet: ICM-20948 DataSheet

Applications

- IoT
- Wearable
- Drone

Solution Benefits

- Lowest power 9-axis solution in the world
- P2P compatible with the MPU-9250
  - 1/3 less power then previous solution
- Supports FSYNC for EIS



ICP-101xx

Barometric Pressure and Temperature Sensor

In Production

Solution Features

- Pressure Operating Range: 300hPa – 1100hPa
- Relative Pressure Accuracy: **±1Pa** (10hPa change,700-1000hPa)
- Pressure Noise RMS and Current Consumption:
  - Low-Power Mode: **3.2Pa at 1.3µA**
  - Low-Noise Mode: **0.8Pa at 5.2µA**
  - Ultra Low-Noise Mode: **0.4Pa at 10.4µA**
- Absolute Pressure Accuracy: ±1hPa (300hPa-1100hPa,0ºC-65ºC)
- Pressure Sensor Tempco: ±0.5Pa/ºC (25ºC-45ºC, 100kPa)
- Temperature Sensor Accuracy: ±0.4ºC
- Operating Temp & Voltage: -40ºC-85ºC, 1.8V ±5%
- Host Interface: I²C up to 400kHz

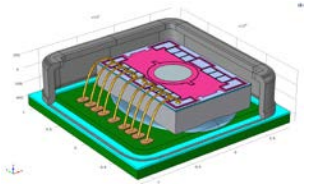
PACKAGE	3-HOLE IPX8: 1.5m WATERPROOF	1-HOLE
2x2x0.72mm 10L LGA	ICP-10100	ICP-10101
2x2.5x0.92mm 8L LGA	ICP-10110	ICP-10111

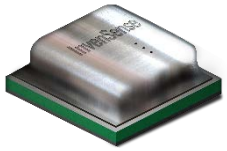
Applications

- Drones
- Mobile Phones
- Fitness Bands/Trackers
- Virtual Reality Headsets/Controllers
- Elderly Fall Detection
- Security Systems
- Hard Drives & Servers

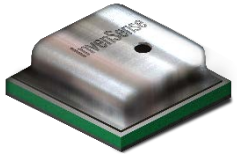
Solution Benefits

- Completely integrated & calibrated pressure and temp sensor IC provides quick time-to-market
- Detect Z-height of 8cm for accurate motion measurements: navigation, dead-reckoning, floor detection, fitness recognition
- Lower power consumption extends battery life or improved accuracy at same power consumption
- Three-0.025mm holes reduce liquid intrusion

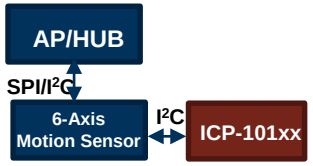


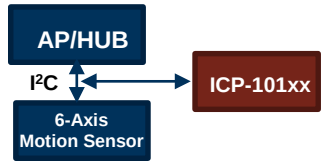


3-Hole: IPx8 Compliant Waterproof to 1.5m Depth



Single Hole Package





ICM-20789

In Production

7-Axis: 6-Axis Motion Sensor and Barometric Pressure Sensor

Solution Features

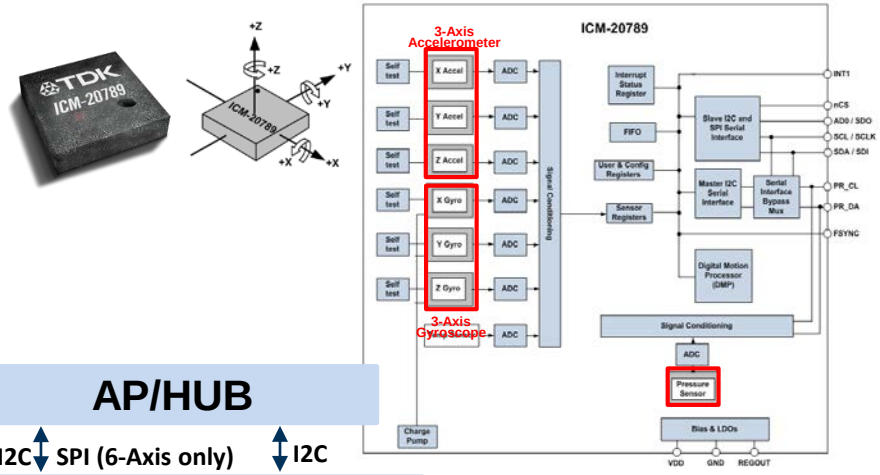
- Digital Motion Processor (DMP) for autonomous operation
- Programmable interrupts, filters, and 4k-byte FIFO
- Gyroscope Full-Scale Range: ±250/500/1000/2000 deg/sec
- Accelerometer Full-Scale Range: ±2/4/8/16 g
- Pressure Operating Range: 300hPa – 1100hPa
- Relative Pressure Accuracy: **±1Pa** (10hPa change,700-1000hPa)
- Absolute Pressure Accuracy: ±1hPa(300hPa-1100hPa,0ºC-65ºC)
- Temperature Sensor Accuracy: ±0.4ºC
- Operating Temperature Range: -40ºC-85ºC
- Operating Voltage Range:
  - VDD 1.7V – 3.45V
  - VDDIO: 1.8V ±5%
- Host Interface: SPI 8MHz, I²C up to 400kHz
- Packages: 4 x 4 x 1.365mm 24-pin LGA

Applications

- Drones
- Motion-based controllers
- Mobile Phones
- Virtual Reality Headsets/Controllers
- Toys

Solution Benefits

- Integrated & calibrated Accel+Gryo+Pressure+Temp sensor provides quick time-to-market in small footprint
- Allow host to sleep/save power while monitoring motion
- Detect Z-height of 8cm for accurate motion measurements: navigation, dead-reckoning, floor detection, fitness recognition
- Lower power consumption extends battery life
- Easy migration from 6-Axis motion sensor to 6-Axis+Pressure



Success Stories

Wrist Worn Drone
MPU-9250

Drone
MPU-6000

Drone
ICM-20602

Vacuum:
MPU-6000

Drone + Controller:
MPU-6000 and MPU-6515

Education Robot:
MPU-6500

Pro Series Drone:
ICM-20789

Success Stories (cont.)

Helmet Camera:
MPU-6500

Gaming Controller:
MPU-6500

AR/VR:
ICM-20608-B

Smart Jacket:
ICM-20648

Senior Wearable:
MPU-9250

VR Headset: ICM-20602;
Touch Controller: MPU-6500T

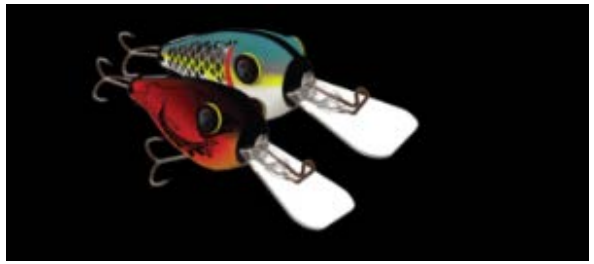
Success Stories (cont.)

AR/VR Headset:
MPU-9250

Wearable modules:
ICM-20601

Personal Theater:
ICM-20603

Swing Analyzer:
ICM-20649



Smart Lure:
ICM-20948

Smart Goggles:
ICM-20948

Motion Sensor Development Tools

SmartMotion Platform

TDK InvenSense SmartMotion® Platform

User Friendly Development Platform for TDK InvenSense 6-Axis, 7-Axis, 9-Axis, and 1-Axis Motion Sensor

https://www.avnet.com/wps/portal/abacus/manufacturers/m/tdk-invensense/smartmotion%C2%AE-development-kits/

Contents	Description
Protective Packaging	The SmartMotion Platform come in a sturdy easy to carry box with protective foam. Please reference MEMS Handling Guide on how to prevent damage to MEMS sensors.
SmartMotion Platform	The SmartMotion board comes with the latest MotionLink software tool pre-flashed on the MCU. The board is configured with default jumper settings.
QuickStart Guide	Instructions to for platform bring up with links to software downloads

SmartMotion® Platform

- Single Board “Out of the Box” experience
  - Microchip G55 MCU + TDK InvenSense Motion Sensor
- On-board embedded debugger
  - Saves ~ €100for external debugger
  - Simpler set up/no cables for debugger
  - Program and debug the MCU
- Affordable – From €70 through Avnet Abacus
  - Customers can buy multiple platforms to speed up development
- Scalable design
  - Supports legacy and future motion sensors
  - WiFi/BLE support with external modules from Microchip
- Less than 15 minutes to set-up

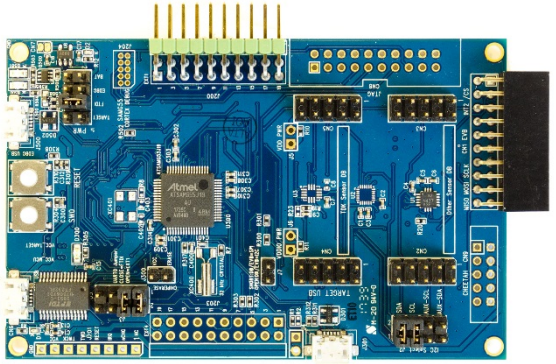
SmartMotion Platforms

SmartMotion™ Platform – 6 Axis

DK-20602

DK-20648

DK-20680A

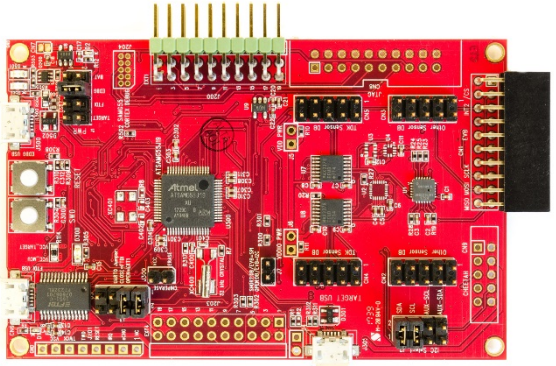


SmartMotion™ Platform – 7, 9, and 1 Axis

DK-20789

DK-20948

DK-10100



SmartMotion Platform

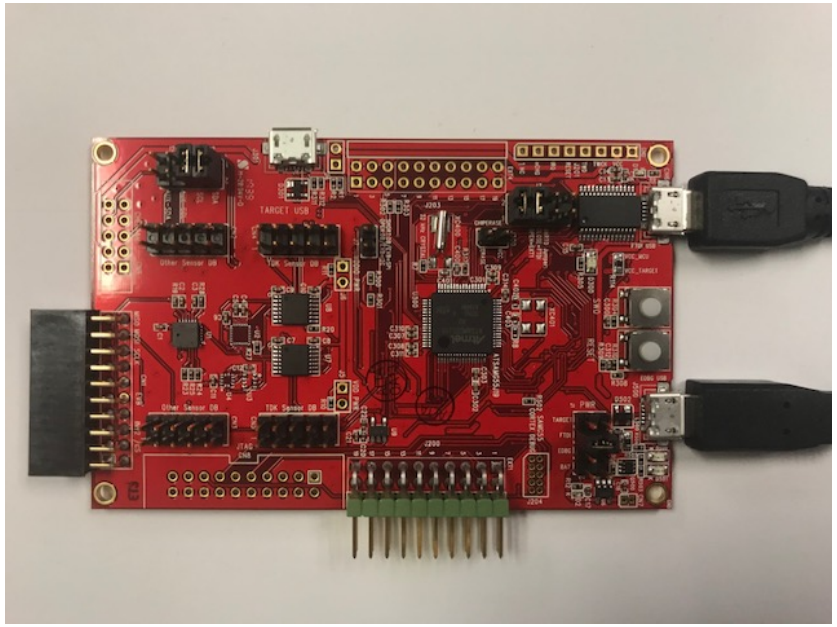
The various SmartMotion Platforms are easily purchasable at the following website from €70

www.avnet.com/wps/portal/emea

Keywords = DK-20602, DK-20648, DK-20789, DK-20948, DK-10100, DK-20680

It’s so Simple!

- Connecting the Boards
  - PC/Laptop – preferably running Win 7
  - Micro-USB cables –
    - FTDI USB Connector (CN6) to PC – Required for default power and most data output
    - EDGB USB Connector (J500) to PC – Optional, only needed if customers planning to flash or trace code. For eMD can be used this output for debug message outputs.



Software Evaluation Tools

2 Software Packages

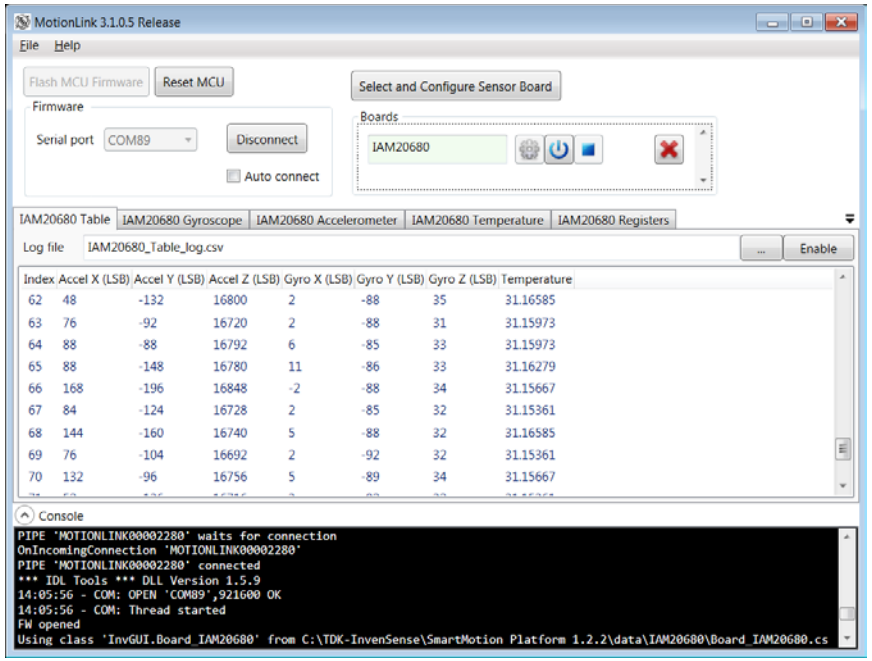
- SmartMotion Installer with MotionLink
- Embedded Motion Drivers (eMDs)
- Both tools available for free download at the TDK-InvenSense Developer's Corner (requires registration)

https://www.avnet.com/wps/portal/abacus/manufacturers/m/tdk-invensense/smartmotion%C2%AE-development-kits/

Software Evaluation Tools

The MotionLink - Hardware Evaluation Tool

- PC Based Software with following features –
  - ¬ Read Register Map Values
  - ¬ Simple I2C read and writes
  - ¬ Display raw sensor data up to 1Khz sample rate
  - ¬ Log Data to text file
  - ¬ Display graphical sensor data



- Why MotionLink? –
  - ¬ Evaluate and log raw gyro, accel, and other sensor data
  - ¬ Will support all channel motion parts

Software Evaluation Tools

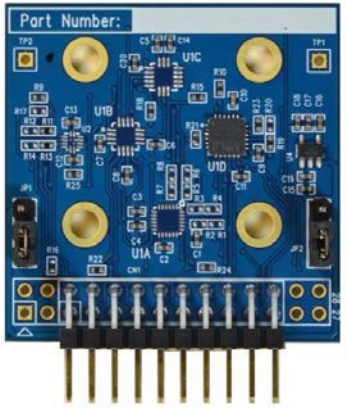
The Embedded Motion Driver (eMD) for SmartMotion Platforms

- Motion Software (dependent on product) can include these features…
  - ¬ Initialization and configuration
  - ¬ Raw Sensor Data streaming
  - ¬ Sensor Fusion output
  - ¬ Gesture Tracking
  - ¬ DMP Image (if applicable)
  - ¬ Factory Test and Calibration
  - ¬ In-Use Calibration
  - ¬ Wake-On-Motion

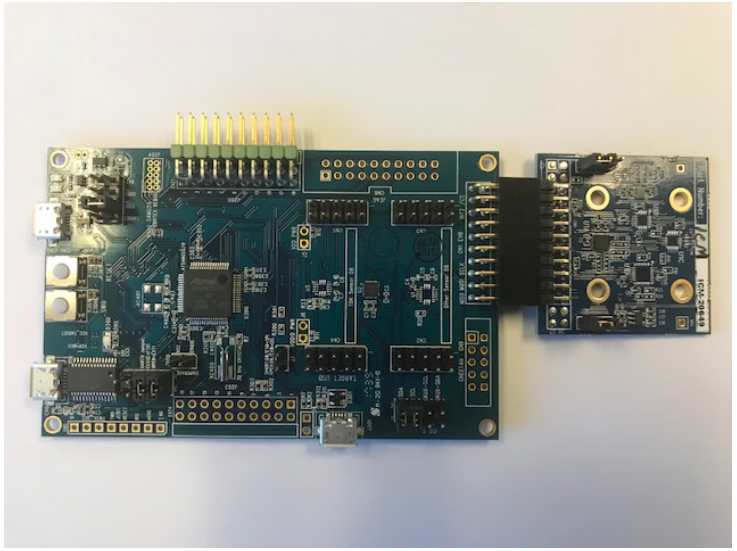
- Currently supported SmartMotion eMDs
  - ¬ ICM20602
  - ¬ ICM20648
  - ¬ ICM20948
  - ¬ ICM20789
  - ¬ ICP-10100
  - ¬ IAM-20680

Evaluating Corona…

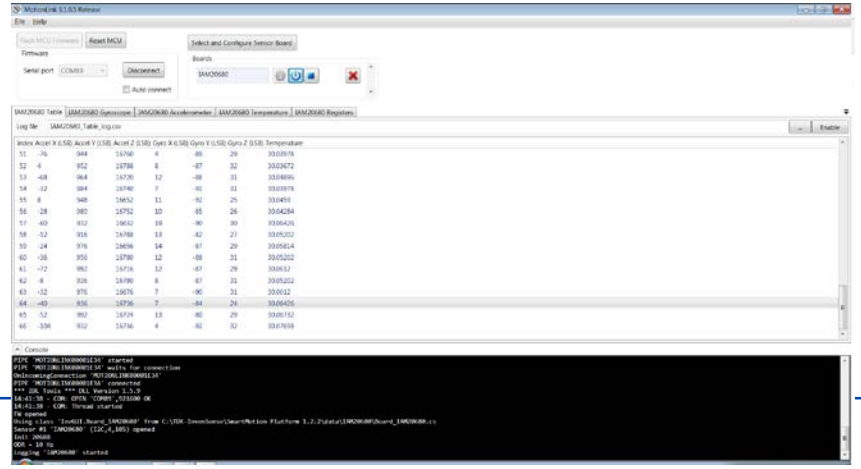
EVBs available at Mass Production at InvenSense Distributors



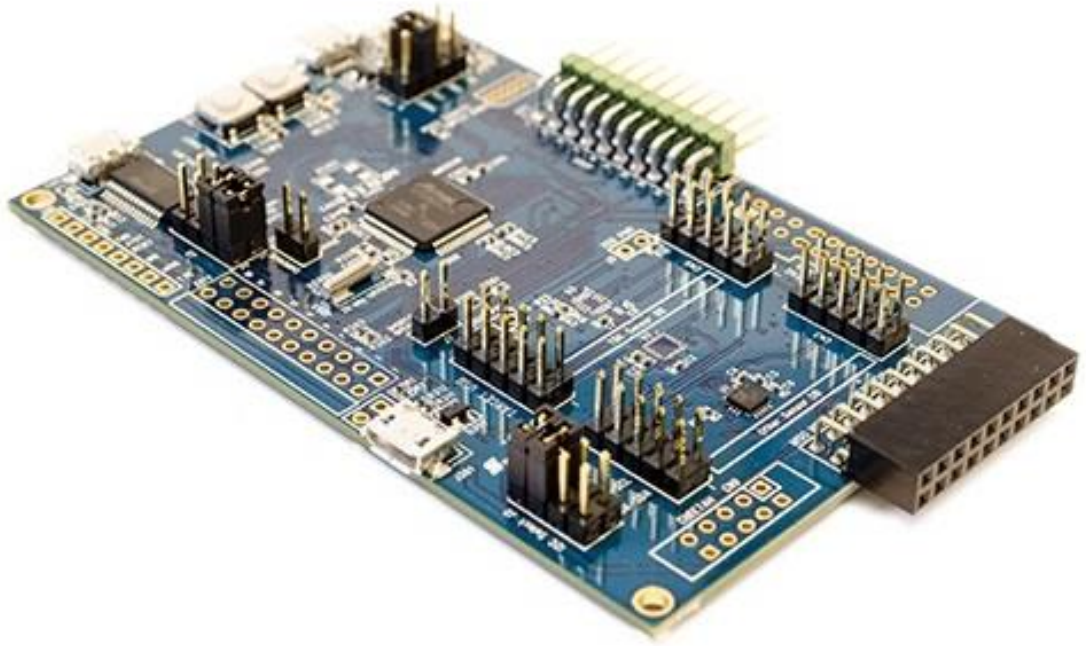
Connect with any SmartMotion DK board



Evaluate with MotionLink!



The DK-42605 available soon after MP!! (…with eMD)



TDK-InvenSense SmartMotion Support

- **Avent SmartMotion Website:**
  https://www.avnet.com/wps/portal/abacus/manufacturers/m/tdk-invensense/smartmotion%C2%AE-development-kits/

- **General Tech Support: www.avnet-abacus.eu/ask-an-expert**

www.invensense.com