# AN1440

# Implementing Motion Sensing Capabilities on PIC24 Microcontrollers

*Author: S. Allen*
*Microchip Technology Inc.*

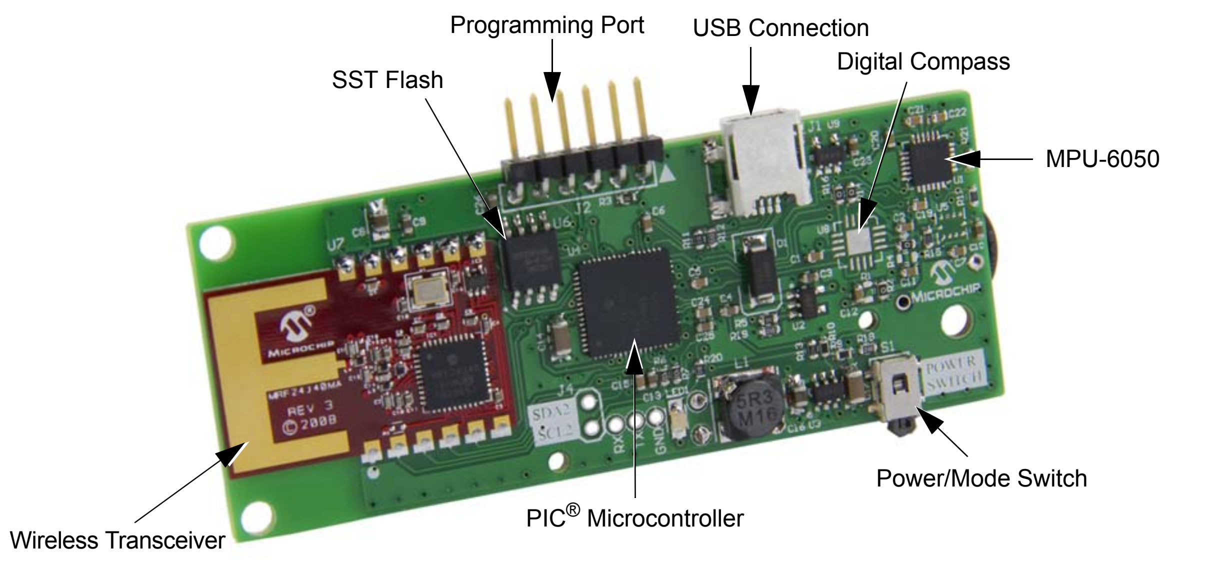
## INTRODUCTION

This Application Note describes the interface with an MPU-6050, the single-chip, 3-axis gyroscope and 3-axis accelerometer from InvenSense®.

The InvenSense MPU-6050 contains a 3-axis MEMS gyroscope, a 3-axis MEMS accelerometer and a Digital Motion Processor™ (DMP). The device is accessed by the PIC® MCU through an I²C™ bus.

The Microchip Motion Sensor Demonstration Board has been designed so that embedded developers who wish to take advantage of motion sensing can greatly reduce development time. The primary components are the PIC24FJ256GB206 microcontroller and the InvenSense MPU-6050 motion processor (Figure 1).

**FIGURE 1: SENSOR BOARD COMPONENT LAYOUT**




**Performance Requirements:**

Minimum recommended RAM: 8 Kbytes

Minimum recommended program memory: 64 Kbytes

Minimum recommended processor speed:
2 MHz (1 MIPs)

The Motion Sensor Demonstration Board contains the following motion sensing devices:

- 6-axis gyroscope/accelerometer
- 3-axis digital compass

In addition, the Motion Sensor Demonstration Board contains a serial Flash memory (SST25VF016B) for storage of sensor data. The Motion Sensor Demonstration Board also contains an AKM AK8975 digital compass. This component is not currently supported by the firmware, but is accessible over the I²C bus.

This system uses InvenSense "sensor fusion" technology to combine the sensor data and create a real-time measurement of the rotation (3-dimensional orientation) of the sensor board. While 9-axis sensor fusion is possible, this implementation utilizes the 6-axis build of the InvenSense Embedded MotionApps™ Platform Release 2.0.0.

The Motion Sensor Demonstration Board has two operating modes and these are selected by commenting/uncommenting them in "`main.c`". Only one mode can be uncommented at any given time.

## MODES OF OPERATION

### Hard-Wired USB Operation

In this mode, the Motion Sensor Demonstration Board is connected to the PC through a USB cable. The Motion Sensor Demonstration Board receives its power through the USB cable and sends angular frame data via the USB connection. The hard-wired USB mode also supports the option of storing sensor data in an on-board Flash memory. To enable this mode, the “Operating Mode Definitions” (in `main.c`) should appear as follows:

```
//#define WIRELESS_TRANSCEIVER
#define USB_HARD_WIRED
```

### Wireless Operation

In this mode, power is supplied from an AAA battery and position information is transmitted using Microchip’s proprietary MiWi™ P2P protocol. To enable this mode, the “Operating Mode Definitions” (in `main.c`) should appear as follows:

```
#define WIRELESS_TRANSCEIVER
//#define USB_HARD_WIRED
```

### System Messages via UART Connection

The Motion Sensor Demonstration Board has connections for UART TX and RX signals (57600 Baud). These connections can be used to send messages from the demo board to a PC terminal application and contain messages that relate to the operation of the demo board. Messages include initialization operations on the Motion Processing Unit™ (MPU) and state messages. These messages are useful for understanding system operation and debugging purposes. Signals are TTL level and will need to be converted to RS-232 to be used by a PC terminal application. The user can also add their own messages to aid application development. For example, the ‘C’ code below sends a message to the terminal application when the Motion Sensor Demonstration Board is in a low-power state:

```
MPL_LOGE("I am in low power state\ n");
```

## INSTALLATION AND USE

### Hard-Wired USB Operation

| **Note:** | The Motion Sensor Demonstration Board, by default, is programmed to run in the wireless mode of operation. To run in hard-wired mode requires that the unit be programmed with the hex file: `motionsense-hardwired.hex`. |
|---|---|

For hard-wired USB operation, the demonstration board receives its power through the USB cable. The Motion Sensor Demonstration Board can either transmit sensor data over the USB cable or store sensor data in the on-board Flash memory. The "power switch" serves the function of toggling between these two modes of operation. The first press of the power button will start recording all data to the Flash memory. The second press of the button will stop recording and start playback. After playback has finished, the board will resume normal operation.

### Interfacing with the MPU-6050

Communication is done with the MPU-6050 via an $I^2C$ interface. The $I^2C$ clock and data pins are mapped to remappable pins, RP17 and RP10, respectively. The $I^2C$ bus uses 4.7 kOhm pull-up resistors on both lines.

The interface to the MPU-6050 was implemented using the InvenSense® Embedded MotionApps™ Platform Release 2.0.0. This implementation is written in 'C' programming language and requires platform dependent commands (MLSL and MLOS components) written for the specific processor. For the PIC24, these files are "`mlsl_pic24.c`" and "`mlos_pic24.c`". These files contain the $I^2C$ interface code and delay functions, which allow the higher level application code to run. The code should be able to be easily ported to any PIC24 device, provided that program and data memory requirements are met.

Quaternion data is retrieved using the "`inv_get_quaternion(longquat)`" function and this will store the Quaternion data as 32-bit integers in the longquat[4] array.

### Interfacing with the AK8975 Digital Compass

Some basic routines have been provided for interfacing with the digital compass. These include:

- `ReadCompassID()` reads the ID value from the digital compass
- `CompassSingleMeasure()` starts conversion process and loads output registers.
- `CompassReadings()` reads Compass Data registers.

The AK8975 can be used for 9-axis sensor fusion, however, the InvenSense Embedded MotionApps™ Platform Release 2.0.0. only supports 6-axis sensor fusion.

### MRF24J40MA Wireless Module

The MRF24J40MA wireless module is a 2.4 GHz IEEE 802.15.4 radio transceiver module, and is used to transmit Quaternion data to the ZENA™ wireless adapter. The motion sensor implementation uses the P2P broadcast method of communication on Channel 13. The channel can be changed on the Motion Sensor Demonstration Board by changing:

```
BYTE myChannel = 13;
```

in `main.c` in the "`StartMiWiConnection`" routine. The same corresponding change will need to be made in the source code for the ZENA wireless adapter.

### ZENA Wireless Adapter

The ZENA wireless adapter contains an MRF24J40MA wireless module and is used to receive Quaternion data from the Motion Sensor Demonstration Board. Full specifications for the MRF24J40MA can be found on the Microchip web site: http://www.microchip.com.

### `HardwareProfile.c`

`HardwareProfile.c` contains most of the processor-specific items for the PIC24FJ256GB206. If you are porting this code to another PIC24 processor, this file is a good starting point for adapting to the processor of your choice. Remappable pins, port setup and peripheral configuration are handled in this file. Timer1 is established so that it can be used by the `inv_sleep` (delay routine used by InvenSense Embedded MotionApps™ Platform). Timer4/5 are used to implement the blink codes for the on-board LED.

### Recording and Playback

In Hard-Wired USB mode, an on-board 2-Mbyte Flash can be used to record movements and then play them back. The high-performance SST Flash (SST25VF016B) can record approximately 20 minutes of activity. The initial press of the power switch will start the recording process. The next press of the power switch will start the playback process. At the first step of the recording process, the entirety of the Flash memory is erased. Because the erase only takes about 30 ms, this is not apparent to the user. After the memory is erased, the Motion Sensor Demonstration Board will start storing Quaternion data in sequential locations, beginning at Address 0. Playback starts at Address 0 and stops when no more valid records are found in the Flash memory.

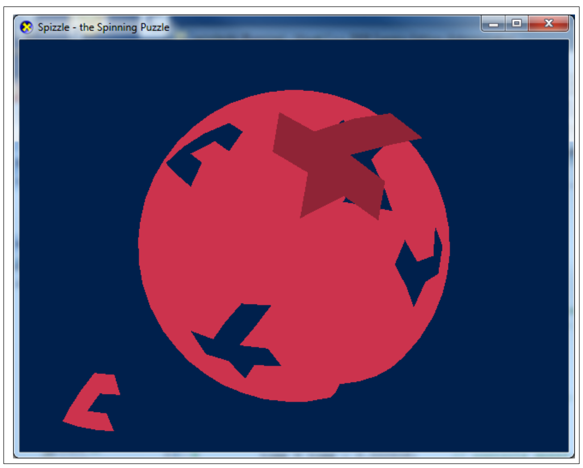
## SPIZZLE INSTRUCTIONS

Spizzle (Spinning Puzzle) is a PC application where you rotate a spherical puzzle and try to line it up for the approaching/matching pieces. This gaming application will only run on Windows® 7 and Windows Vista® operating systems. As soon as you line up the sphere with a matching piece, it will quickly drop into its location and become a part of the sphere. Then, the next piece will appear and this process continues until the sphere is complete.

At the beginning of the game, determine where the "front" of the sphere is located. The top of the sphere is absolute, but the rotation needs to be determined. Rotate the sphere around the vertical axis, and complete up/down rotations, until you find that the sphere matches your movements. After you have oriented the sphere, it should be much easier to align the sphere to the incoming piece.

In Figure 2, the dark red piece is approaching the sphere and its matching space is below it (approximately 180 degrees off).

**FIGURE 2: SPIZZLE GAMEPLAY**




| **Note:** | The next piece is displayed in the lower left corner of the screen. |
|---|---|

## DATA FORMATTING

In order to express the rotation of an object, there are many possible data formats to choose. One way of expressing rotation is through roll, pitch and yaw. Expressing rotational data in this manner leaves the possibility of a "gimbal lock", where a degree of freedom is lost. The best way to express rotations is through Quaternions. A Quaternion has the following properties:

- A Quaternion holds rotational data in a compact manner.
- A Quaternion provides a mechanism to easily rotate a point in 3-dimensional space without the use of trigonometric functions.
- It is very simple to take an axis/angle of rotation and generate a Quaternion.
- Quaternions are stable structures that provide a smooth, continuous space for rotational data.

Because of the above, the use of Quaternions has become popular for computer gaming and for motion sensing applications. A Quaternion can be expressed as 4 numbers:

$Q = q_0 + q_1\hat{i} + q_2 k + q_3\hat{j}$

And has the property that $q_0^2 + q_1^2 + q_2^2 + q_3^2 = 1$

If you are new to Quaternions, don't worry about getting bogged down in complex math. Just think of them as a tool that will store your rotational data. Most modern graphics programs, such as Direct3D® and OpenGL® also have support for the Quaternion data format.

The routine, "`QuatSend`", will generate the Quaternion data as non-normalized integers. In order to normalize the Quaternion data, you need to do two things:

1. If any term is greater than 32,767, subtract 65,536 from that term.
2. Divide each term by 16,384.

This should produce a 4-element Quaternion with a magnitude equal to 1.

**TABLE 1: BILL OF MATERIALS**

| Qty | Designator | Value | Description | Part Number |
|---|---|---|---|---|
| 1 | BAT1 | | Battery Holder, AAA Plastic, Keystone | 2467 |
| 11 | "C1, C2, C5, C6, C7, C11, C12, C15, C20, C21, C24" | 0.1 µF | CAP CERAMIC.1UF 16V Y5V 0603 | CC0603ZRY5V7BB104 |
| 8 | "C3, C4, C9, C10, C13, C23, C25, C26" | 1 µF | CAP CER 1.0UF 16V 10% X5R 0603 | GRM188R61C105KA93D |
| 2 | "C8, C16" | 10 µF | CAP CER 10UF 6.3V Y5V 0805 | GRM21BF50J106ZE01L |
| 2 | "C14, C17" | 10 µF | CAP CER 10UF 16V X5R 10% 1206 | C3216X5R1C106K |
| 2 | "C19, C22" | 10 nF | CAP CER.01UF 50V X7R 0603 | 160R14W103KV4T |
| 1 | D1 | | DIODE STD REC 1A 300V SMA | MRA4003T3G |
| 1 | J1 | | CONN RECEPT MINI USB2.0 5POS | UX60-MB-5ST |
| 1 | J2 | | CONN HEADER 6POS.100" SGL GOLD | TSW-106-07-G-S |
| 1 | L1 | 5.3 µH | Power Inductors 5.3uH 1.90A | CDRH5D28NP-5R3NC |
| 1 | LED1 | | LED THIN 565NM GRN DIFF 0805 SMD | SML-LXT0805GW-TR |
| 1 | PCB1 | | PCB | |
| 2 | "R1, R4" | No Load | Resistor, No Load | |
| 5 | "R2, R8, R14, R16, R21" | 0 Ohm | RES 0.0 OHM 1/10W 0603 SMD | RMCF 1/16 0 R |
| 2 | "R3, R5" | 10K | RES 10K OHM 1/10W 1% 0603 SMD | RMCF 1/16 10K 1% R |
| 2 | "R6, R7" | 4.7K | RES 4.7K OHM 1/10W 1% 0603 SMD | RMCF 1/16 4.7K 1% R |
| 1 | R9 | 953K | RES 953K OHM 1/10W 1% 0603 SMD | ERJ-3EKF9533V |
| 1 | R10 | 887K | RES 887K OHM 1/10W 1% 0603 SMD | ERJ-3EKF8873V |
| 1 | R11 | 100 Ohm | RES 100 OHM 1/10W 1% 0603 SMD | RMCF 1/16 100 1% R |
| 3 | "R12, R18, R19" | 100K | RES 100K OHM 1/10W 1% 0603 SMD | RMCF 1/16 100K 1% R |
| 1 | R13 | 2.74M | RES 2.74M OHM 1/10W 1% 0603 SMD | CRCW06032M74FKEA |
| 2 | "R15, R17" | 2K | RES 2K OHM 1/10W 1% 0603 SMD | RMCF0603FT2K00 |
| 1 | R20 | 1K | RES 1K OHM 1/10W 1% 0603 SMD | RMCF 1/16 1K 1% R |
| 1 | S1 | | SWITCH LT SIDE 160GF H=1.8MM SMD | EVQ-PSL02K |
| 1 | U1 | | Embedded 3-axis gyroscope, 3-axis accelerometer | MPU-6050 |
| 1 | U2 | | IC REG LDO 300MA 3.3V SOT23-5 | MCP1802T-3302I/OT |
| 1 | U3 | | IC CONV DCDC STEPUP SYNC SOT23-6 | MCP1640T-I/CHY |
| 1 | U4 | | General Purpose 16-Bit Flash Microcontroller with USB On-The-Go, 256KB Flash, 16KB SRAM, 64-Pin QFN, Industrial Temperature | PIC24FJ256GB206-I/MR |
| 1 | U5 | | 2g Tri-axis Digital Accelerometer (optional) | KXTF9-106 |
| 1 | U6 | | 16 Mbit SPI Serial Flash | SST25VF016B-50-4C-S2AF |
| 1 | U7 | | IEEE 802.15.4 2.4 GHz RF Transceiver | MRF24J40MA |
| 1 | U8 | | 3-axis Electronic Compass | AK8975P-L-RD |
| 1 | U9 | | IC EEPROM 8KBIT 400KHZ SOT23-5 | 24LC08BT-I/OT |

NOTES:

**Note the following details of the code protection feature on Microchip devices:**

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip's Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as "unbreakable."

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break Microchip's code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.



**QUALITY MANAGEMENT SYSTEM**
**CERTIFIED BY DNV**
**== ISO/TS 16949 ==**

**Trademarks**



Printed on recycled paper.

ISBN: 978-1-62076-449-7

*Microchip received ISO/TS-16949:2009 certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona; Gresham, Oregon and design centers in California and India. The Company's quality system processes and procedures are for its PIC® MCUs and dsPIC® DSCs, KEELOQ® code hopping devices, Serial EEPROMs, microperipherals, nonvolatile memory and analog products. In addition, Microchip's quality system for the design and manufacture of development systems is ISO 9001:2000 certified.*

# Worldwide Sales and Service


## AMERICAS

**Corporate Office**
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200
Fax: 480-792-7277
Technical Support:
http://www.microchip.com/support
Web Address:
www.microchip.com

**Atlanta**
Duluth, GA
Tel: 678-957-9614
Fax: 678-957-1455

**Boston**
Westborough, MA
Tel: 774-760-0087
Fax: 774-760-0088

**Chicago**
Itasca, IL
Tel: 630-285-0071
Fax: 630-285-0075

**Cleveland**
Independence, OH
Tel: 216-447-0464
Fax: 216-447-0643

**Dallas**
Addison, TX
Tel: 972-818-7423
Fax: 972-818-2924

**Detroit**
Farmington Hills, MI
Tel: 248-538-2250
Fax: 248-538-2260

**Indianapolis**
Noblesville, IN
Tel: 317-773-8323
Fax: 317-773-5453

**Los Angeles**
Mission Viejo, CA
Tel: 949-462-9523
Fax: 949-462-9608

**Santa Clara**
Santa Clara, CA
Tel: 408-961-6444
Fax: 408-961-6445

**Toronto**
Mississauga, Ontario, Canada
Tel: 905-673-0699
Fax: 905-673-6509

## ASIA/PACIFIC

**Asia Pacific Office**
Suites 3707-14, 37th Floor
Tower 6, The Gateway
Harbour City, Kowloon
Hong Kong
Tel: 852-2401-1200
Fax: 852-2401-3431

**Australia - Sydney**
Tel: 61-2-9868-6733
Fax: 61-2-9868-6755

**China - Beijing**
Tel: 86-10-8569-7000
Fax: 86-10-8528-2104

**China - Chengdu**
Tel: 86-28-8665-5511
Fax: 86-28-8665-7889

**China - Chongqing**
Tel: 86-23-8980-9588
Fax: 86-23-8980-9500

**China - Hangzhou**
Tel: 86-571-2819-3187
Fax: 86-571-2819-3189

**China - Hong Kong SAR**
Tel: 852-2401-1200
Fax: 852-2401-3431

**China - Nanjing**
Tel: 86-25-8473-2460
Fax: 86-25-8473-2470

**China - Qingdao**
Tel: 86-532-8502-7355
Fax: 86-532-8502-7205

**China - Shanghai**
Tel: 86-21-5407-5533
Fax: 86-21-5407-5066

**China - Shenyang**
Tel: 86-24-2334-2829
Fax: 86-24-2334-2393

**China - Shenzhen**
Tel: 86-755-8203-2660
Fax: 86-755-8203-1760

**China - Wuhan**
Tel: 86-27-5980-5300
Fax: 86-27-5980-5118

**China - Xian**
Tel: 86-29-8833-7252
Fax: 86-29-8833-7256

**China - Xiamen**
Tel: 86-592-2388138
Fax: 86-592-2388130

**China - Zhuhai**
Tel: 86-756-3210040
Fax: 86-756-3210049

## ASIA/PACIFIC

**India - Bangalore**
Tel: 91-80-3090-4444
Fax: 91-80-3090-4123

**India - New Delhi**
Tel: 91-11-4160-8631
Fax: 91-11-4160-8632

**India - Pune**
Tel: 91-20-2566-1512
Fax: 91-20-2566-1513

**Japan - Osaka**
Tel: 81-66-152-7160
Fax: 81-66-152-9310

**Japan - Yokohama**
Tel: 81-45-471- 6166
Fax: 81-45-471-6122

**Korea - Daegu**
Tel: 82-53-744-4301
Fax: 82-53-744-4302

**Korea - Seoul**
Tel: 82-2-554-7200
Fax: 82-2-558-5932 or
82-2-558-5934

**Malaysia - Kuala Lumpur**
Tel: 60-3-6201-9857
Fax: 60-3-6201-9859

**Malaysia - Penang**
Tel: 60-4-227-8870
Fax: 60-4-227-4068

**Philippines - Manila**
Tel: 63-2-634-9065
Fax: 63-2-634-9069

**Singapore**
Tel: 65-6334-8870
Fax: 65-6334-8850

**Taiwan - Hsin Chu**
Tel: 886-3-5778-366
Fax: 886-3-5770-955

**Taiwan - Kaohsiung**
Tel: 886-7-536-4818
Fax: 886-7-330-9305

**Taiwan - Taipei**
Tel: 886-2-2500-6610
Fax: 886-2-2508-0102

**Thailand - Bangkok**
Tel: 66-2-694-1351
Fax: 66-2-694-1350

## EUROPE

**Austria - Wels**
Tel: 43-7242-2244-39
Fax: 43-7242-2244-393

**Denmark - Copenhagen**
Tel: 45-4450-2828
Fax: 45-4485-2829

**France - Paris**
Tel: 33-1-69-53-63-20
Fax: 33-1-69-30-90-79

**Germany - Munich**
Tel: 49-89-627-144-0
Fax: 49-89-627-144-44

**Italy - Milan**
Tel: 39-0331-742611
Fax: 39-0331-466781

**Netherlands - Drunen**
Tel: 31-416-690399
Fax: 31-416-690340

**Spain - Madrid**
Tel: 34-91-708-08-90
Fax: 34-91-708-08-91

**UK - Wokingham**
Tel: 44-118-921-5869
Fax: 44-118-921-5820


11/29/11