Universidad de Costa Rica
Escuela de Ingeniería Eléctrica
IE0624 - Laboratorio de Microcontroladores

Laboratorio 5
STM32/Arduino: GPIO, Giroscopio, comunicaciones, TinyML

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Introducción

En este documento se presenta la solución realizada para el Laboratorio 5 del curso Laboratorio de Microcontroladores. El laboratorio consiste en el desarrollo de un HAR (Human Activity Recognition) utilizando el microcontrolador SMT32F429 Discovery como en laboratorios anteriores o el kit de Tiny Machine Learning con el Arduino Nano 33 BLE.

Para llevar a cabo el reconocedor de actividad humana primero se realizó un programa para que el microcontrolador seleccionado capture la información del giroscopio y la envie a la computadora a través del puerto USB. Para esto se utilizó un script de Python similar al implementado en laboratorios anteriores del curso. Este script se encarga de guardar la información recibida del giroscopio, realiza un ordenamiento de los datos y los etiqueta con el tipo de movimiento que se esta efectuando en un archivo de extensión CSV. Los movimientos que se van a registrar son círculos, flexiones y estacionarios por un periodo de tiempo de 5 a 15 segundos aproximadamente. Todo eso sucede mientras se encuentra en ejecución el programa de registro del giroscopio con el script de comunicaciones a la PC.

Todos los recursos asociados a la solución desarrollada se encuentran en el repositorio a continuación: `https://github.com/yennergonzalez/Laboratorio_Microcontroladores_5`

Nota teórica

Arduino Nano 33 BLE

El Nano 33 BLE Sense es un módulo de tamaño miniatura que contiene un módulo NINA B306, basado en Nordic nRF52480 y que contiene un procesador Arm Cortex-M4F (64MHz), una memoria de 1 MB Flash + 256 KB RAM, un crypto chip que puede almacenar de forma segura certificados y claves precompartidas y una IMU de 9 ejes. Es utilizado especialmente en proyectos, mejoras y en aplicaciones IoT.

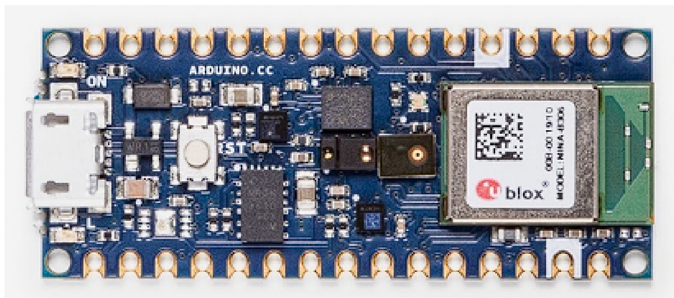


Figura 1: Microcontrolador: Arduino Nano 33 BLE

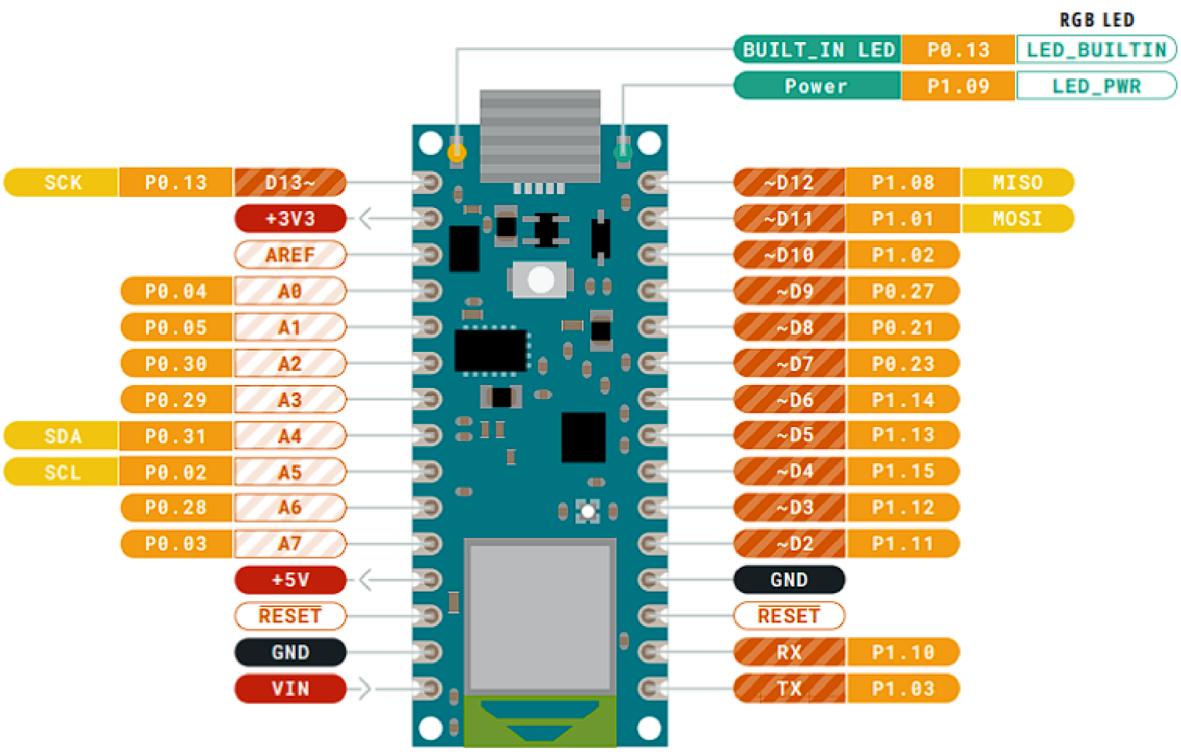


Figura 2: Diagrama de pines de una placa Arduino Nano 33 BLE

Condiciones de operación y características eléctricas del microcontrolador

Symbol	Description	Min	Max
	Conservative thermal limits for the whole board:	-40 °C (40 °F)	85°C (185 °F)

Figura 3: Condiciones de operación

Symbol	Description	Min	Typ	Max	Unit
PBL	Power consumption with busy loop		TBC		mW
PLP	Power consumption in low power mode		TBC		mW
PMAX	Maximum Power Consumption		TBC		mW

Figura 4: Carácteristicas eléctricas

Periféricos

LSM9DS1

El LSM9DS1 es un componente system-in-package que incluye un sensor de aceleración lineal digital 3D, un sensor de velocidad angular digital 3D y un sensor magnético digital 3D. Incluye una interfaz de bus serie I2C compatible con el modo estándar y rápido (100 kHz y 400 kHz) y una interfaz SPI. Se caracteriza por tener una gestión inteligente de energía para habilitar o configurar la detección magnética, el acelerómetro y el giroscopio.

Es utilizado comúnmente en aplicaciones de navegación en interiores, interfaces de usuario inteligente, reconocimiento de gestos avanzado, en dispositivos de entrada para videojuegos y realidad virtual y visualización u orientación en el mapa y navegación.

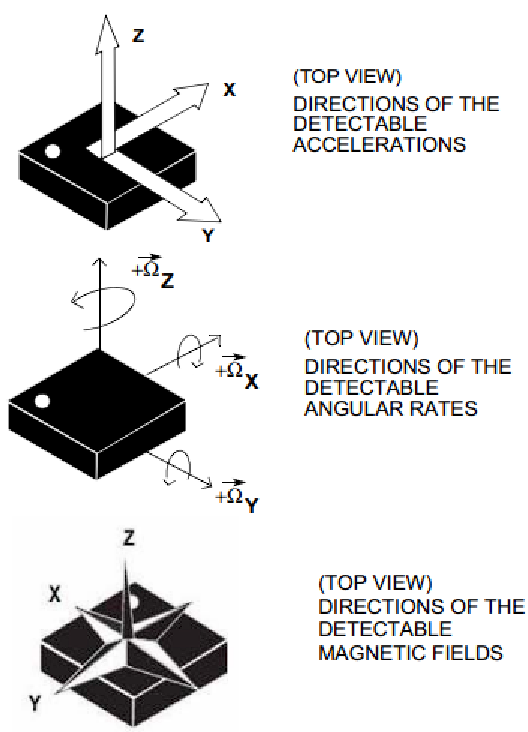


Figura 5: Características del giroscopio LSM9DS1

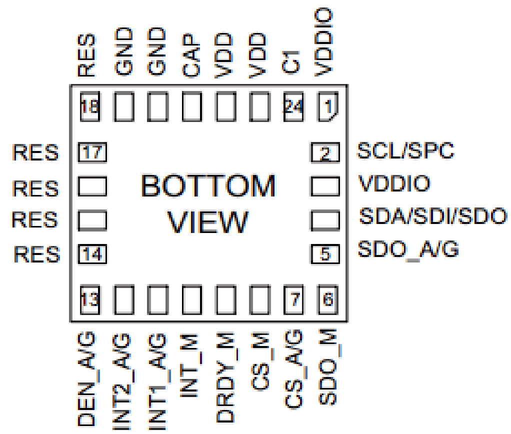


Figura 6: Pines del giroscopio LSM9DS1

Condiciones de operación y características eléctricas del LSM9DS1

Part number	Temperature range [°C]	Package	Packing
LSM9DS1	-40 to +85	LGA-24L	Tray
LSM9DS1TR	-40 to +85	LGA-24L	Tape and reel

Figura 7: Condiciones de operación

Symbol	Parameter	Test conditions	Min.	Typ.(1)	Max.	Unit
Vdd	Supply voltage		1.9		3.6	V
Vdd_IO	Module power supply for I/O		1.71		Vdd+0.1	
Idd_XM	Current consumption of the accelerometer and magnetic sensor in normal mode (2)			600		µA
Idd_G	Gyroscope current consumption in normal mode(3)			4.0		mA
Top	Operating temperature range		-40		+85	°C
Trise	Time for power supply rising(4)		0.01		100	ms
Twait	Time delay between Vdd_IO and Vdd(4)		0		10	ms

Figura 8: Características eléctricas

Diseño del circuito

Para este laboratorio prácticamente todo es implementado a través de la placa de desarrollo.

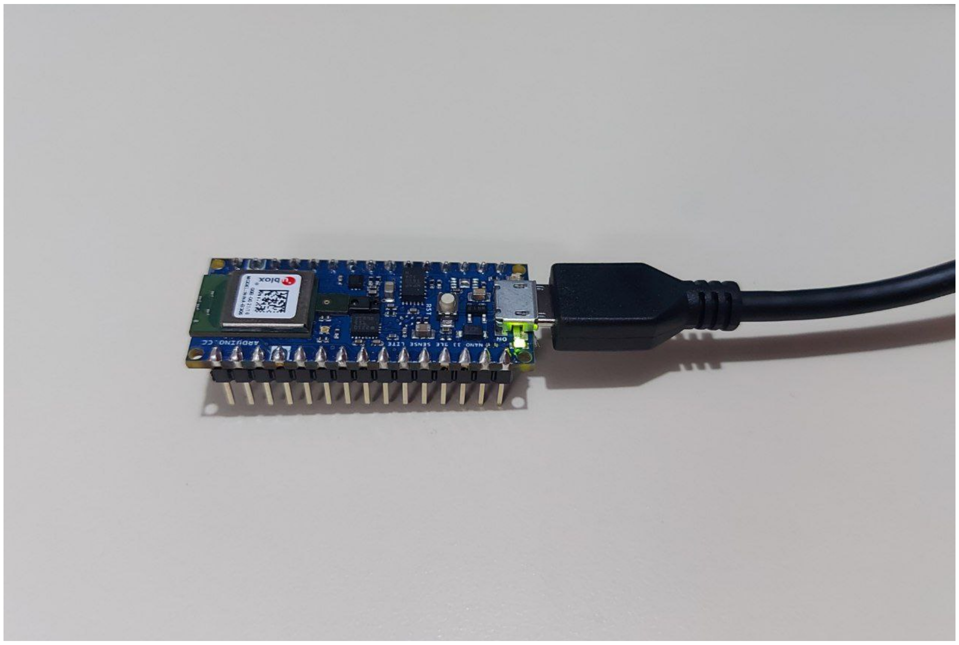


Figura 9: Arduino Nano 33 BLE

Lista de componentes y costos

Cantidad	Componente	Costo unitario
1	STM32F429 Discovery kit	$29.9
1	Arduino Nano 33 BLE	$26.30

Tabla 1: Costos de los componentes utilizados.

Costo total

En la tabla 1 se muestra el precio de los dos microcontroladores con los que se puede realizar el laboratorio. Este fue realmente realizado con un Arduino 33 BLE por lo que el costo total de los componentes utilizados sería de **$26.30**. Este es un precio relativamente accesible.

Conceptos/temas de laboratorio

Machine Learning

Es un subconjunto de la Inteligencia Artificial que se encarga de desarrollar sistemas que aprenden, mejoran el rendimiento, en función de los datos que se le suministran. En la actualidad existen muchos programas que tienen la capacidad de realizar una identificación de patrones de alta complejidad en millones de datos, construyen modelos pero además, generan predicciones de comportamiento futuros.

Tipos de Machine Learning

- Aprendizaje por refuerzo: Es un método de aprendizaje basado en prueba y error hasta que la máquina alcanza la mejor manera de poder completar esa tarea en específico.

- Aprendizaje autónomo supervisado: Se utiliza un algoritmo que se capacita mediante una serie de datos que ya están etiquetados y tienen un resultado predefinido.
- Aprendizaje autónomo no supervisado: El algoritmo es el que se encarga de aprender a identificar procesos y patrones complejos sin que el ser humano lo esté guiando constantemente. Este aprendizaje implica la capacitación basada en datos que no tienen un resultado específico definido.

TinyML

Son modelos de aprendizaje automático adecuados para dispositivos que cuentan con memoria y potencia de procesamiento limitadas. Es utilizado en aplicaciones de complejidad baja como el análisis de los datos de un sensor, reconocimiento de actividades, entre otros. También en aplicaciones de complejidad media y alta como señales de audio, reconocimiento del habla y detección de objetos, rastreo, entre otros.

Pasos generales de TinyML

- Captura de datos
- Limpieza de datos
- Etiqueta de datos
- Construcción de la topología de redes neuronales
- Convertir la red neuronal en código optimizado para MCU
- Procesamiento y análisis de datos usando redes neuronales entrenada.

Human Activity Recognition

También conocido como HAR. Consiste en predecir los movimientos de una persona mediante datos generados por sensores. Requiere de métodos de procesamiento de señales avanzada y con un alto grado de complejidad. Dichos métodos están basados en aprendizaje profundo como redes neuronales convolucionales (CNN) y redes neuronales recurrentes (RNN). Los datos sensados típicamente se separan en sub-secuencias conocidas como ventanas y cada ventana se asocia a una actividad.

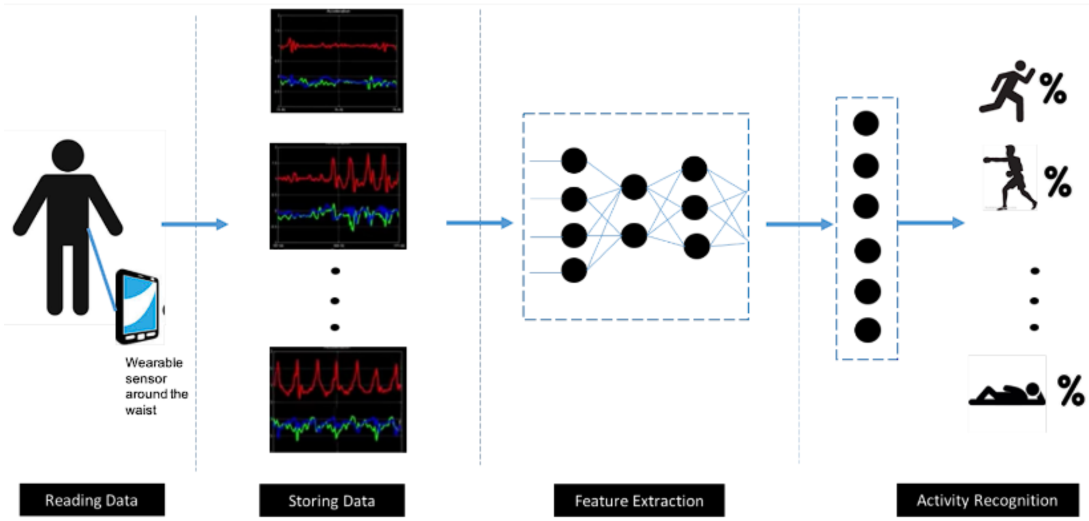


Figura 10: Human Activity Recognition

Beneficios de las redes neuronales

- Utiliza métodos basados en procesamiento de señales que requieren conocimientos en el área para el análisis de datos y la extracción de características.
- Estos métodos han demostrado la capacidad para extraer de manera automática las características y aprender de los datos.
- Existen dos formas de redes neuronales apropiadas para la clasificación de series de tiempo.
- Las RNN y LSTM son recomendadas para el reconocimiento de actividades cortas con un orden natural
- Las CNN muestran capacidades para el aprendizaje de características conectnidas en patrones recursivos.

Desarrollo

Análisis del programa

En esta sección se presenta el razonamiento utilizado para realizar los distintos programas utilizados para el desarrollo del laboratorio. A nivel general este consiste en tres etapas, la primera de obtención de los datos para crear el modelo, el entrenamiento del modelo a partir de los datos recolectados y finalmente la implementación del modelo para detectar nuevos movimientos.

Obtención de datos

Para esta sección se tienen dos programas, el *firmware* del microcontrolador que permite obtener los datos reportados por el acelerómetro y el giroscopio con el fin de enviarlos por el puerto serial y el *script* de python que se conecta al puerto serial para guardar los datos en un archivo *csv*.

Firmware Para el *firmware* se tomó como base el desarrollado previamente por Don Coleman y Sandeep Mistry para el tutorial del Arduino Nano 33 BLE. Este consiste esencialmente en utilizar las funciones `readAcceleration` y `readGyroscope` para obtener las magnitudes de interés para el laboratorio(caracterizan el movimiento que se está realizando) y luego utilizando las funciones `Serial.print` se envían estos datos hacia el puerto serial. (Inicialmente esta parte se realizó utilizando solo el giroscopio sin embargo se encontró que se obtenían mejores resultados al usar el giroscopio y el acelerómetro de manera simultánea)

Script El *script* realizado (`collect_data.py`) consiste en definir un encabezado para todas las magnitudes que se recibirán (6, 3 del acelerómetro y 3 del giroscopio) y luego se utiliza la función `readline()` para ir leyendo la información enviada por el microcontrolador. A esta se le hacen algunas manipulaciones para asegurar que tenga el formato correcto y después de esto se escribe línea por línea en un archivo *csv*. Esto se repite hasta que se tomen 1000 muestras de cada magnitud.

Teniendo cargado el *firmware* en el microcontrolador y ejecutando el *script* de python se registran los datos para tres movimientos distintos: círculos, flexiones y estacionario.

Creación del modelo

Para la creación del modelo se utilizó como base el proyecto de Google Colab `Arduino Tiny ML Workshop` indicado en las presentaciones de clase. Este se modifica para que tome en cuenta las tres clases de movimiento que se pretenden detectar y se le cargan los archivos *csv* de estos datos. El proyecto se encarga de configurar una red neuronal, utilizando `ReLU` para las neuronas intermedias y `softmax` para las de salida.

Al finalizar la ejecución se obtiene un archivo *tflite* y un archivo *h* que corresponden al modelo desarrollado y que se deberán incluir para la siguiente etapa.

Detección de movimientos a partir del modelo

Finalmente, en la última etapa se desarrolla nuevamente un *firmware* (a este se le debe incluir el archivo *h* obtenido en la sección anterior) para implementar el modelo entrenado y luego mediante el puerto serial se envían los datos que serán recibidos por un *script* de python.

El *script* desarrollado para esta parte (`collect_results.py`) es más sencillo que el de la primera parte ya que este simplemente escribe las líneas que recibe en un archivo *txt*, no es necesario realizarle ninguna clase de manipulación adicional. El contenido de este archivo corresponde a un valor entre cero y uno que indica la convicción del modelo sobre la correspondencia del movimiento recién realizado. Un valor mayor indica una mayor convicción de que el movimiento corresponde al predicho.

Análisis del circuito

Para este laboratorio no se incluye mayor información en el análisis del circuito pues todo fue realizado utilizando únicamente la placa de desarrollo Arduino Nano 33 BLE. No fue necesario utilizar ningún circuito adicional.

Resultados

Obtención de los datos para entrenar el modelo

En esta sección se presentan capturas de los archivos *csv* obtenidos cuando se estaban registrando datos para cada uno de los movientos realizados (estacionario, flexión y círculos), además de una gráfica de los valores reportados respecto al tiempo/número de muestra.

flex.csv

1	accx	accy	accz	gyrx	gyry	gyrz
2	0.0325	-0.9457	0.5446	-126.5869	-18.4326	-24.231
3	-0.2239	-1.8463	1.8217	-42.3584	-15.686	-83.0688
4	-0.4059	-1.1409	1.3726	187.1338	-14.9536	85.9985
5	0.2076	0.2394	-0.3204	286.6211	83.9233	122.6196
6	0.3584	0.6932	-2.033	195.9229	65.6128	89.2944
7	0.3043	0.2667	-1.4238	-136.6577	-8.3618	-48.0957
8	0.0388	-0.0094	-0.3979	-228.6377	-63.1104	-109.7412
9	-0.3296	-0.0688	0.5752	-381.0425	-32.3486	-109.1919
10	0.0269	-0.5895	2.1637	-287.2314	-21.2402	-59.8755
11	-0.3788	-1.0739	2.2108	10.1318	-1.6479	11.4136
12	-0.4337	-0.6854	1.9535	210.3882	-10.437	50.1099
13	-0.2502	0.3004	1.1138	346.2524	52.9785	137.146
14	0.2319	0.5669	-0.5397	366.6382	83.9844	99.7314
15	0.1066	0.8301	-1.9718	224.9756	71.0449	33.6914
16	-0.0234	0.2568	-1.5468	-102.356	26.4893	23.7427
17	0.1096	0.0393	-1.1752	-196.4722	15.7471	15.1978
18	0.1119	0.0715	-0.6167	-287.5977	-24.0479	-53.6499
19	-0.3346	0.0634	0.3802	-373.9014	-50.1709	-116.0889
20	-0.4003	-0.395	1.5254	-263.7939	71.3501	3.0518

Figura 11: Datos obtenidos para un movimiento de flexión.

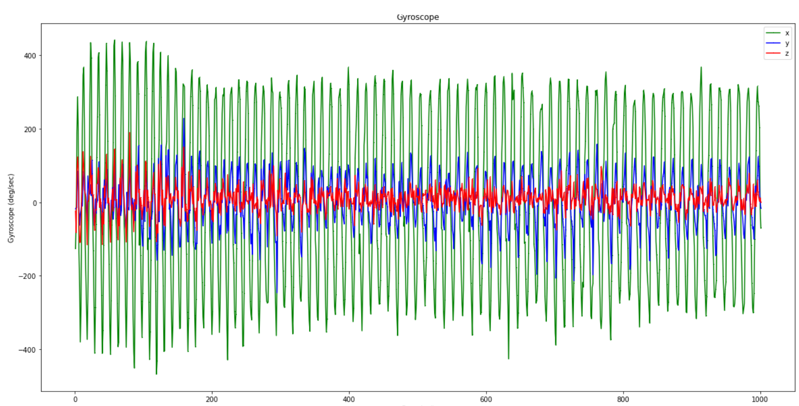


Figura 12: Gráfica de los datos obtenidos para un movimiento de flexión.

circles.csv

1	accx	accy	accz	gyrx	gyry	gyrz
2	1.4521	-0.8427	1.976	-6.2256	-135.6201	28.4424
3	0.7853	-0.3044	2.2789	-25.6958	114.8682	128.2349
4	0.016	0.2268	1.7819	-120.4834	211.9141	140.0757
5	-0.6642	0.2273	0.1903	-249.0234	45.7764	71.167
6	-0.2955	-0.7362	-1.0835	-86.6089	-217.5293	-164.1235
7	1.5403	-1.3953	0.7712	126.8921	-193.0542	-41.687
8	1.3562	-0.3724	2.0153	8.2397	-83.4961	120.1782
9	0.531	0.493	2.2737	-63.0493	150.7568	124.3896
10	-0.126	0.866	1.366	-204.1626	224.9756	73.1812
11	-0.5392	0.067	0.118	-220.0928	124.8169	-65.7959
12	-0.2511	-0.661	-0.5177	-28.6255	-132.3853	-71.9604
13	1.1997	-1.2008	0.2915	88.2568	-264.4043	-54.8706
14	1.923	-0.4432	1.2708	27.9541	-153.6255	61.4014
15	1.2285	0.6769	2.094	5.3101	46.4478	107.7881
16	0.4878	0.8035	1.5714	-73.8525	199.0356	70.2515
17	-0.3837	0.5393	0.4326	-137.3901	205.8716	-24.1089
18	-0.4539	-0.1414	-0.2179	-136.6577	36.0718	-50.9644
19	0.4304	-1.1796	-0.2725	33.6304	-236.3892	-88.9893
20	1.7122	-0.6143	0.5879	121.0938	-164.856	-5.3101

Figura 13: Datos obtenidos para un movimiento de círculos.

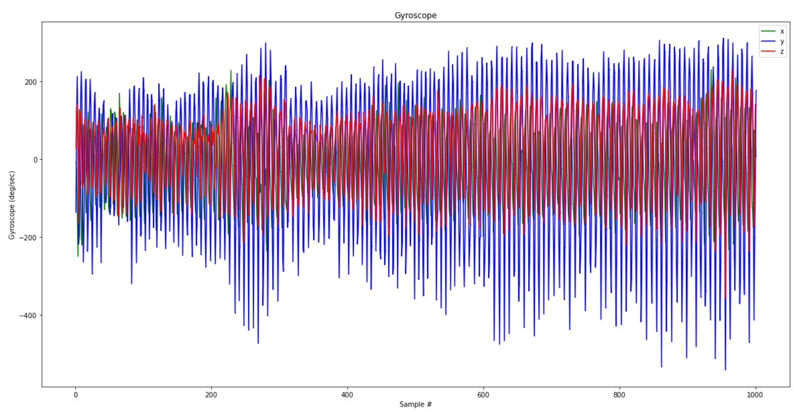


Figura 14: Gráfica de los datos obtenidos para un movimiento de círculos.

stationary.csv

1	accx	accy	accz	gyrx	gyry	gyrz
2	-0.0918	-0.0256	0.9574	0.8545	-0.061	0.3662
3	-0.0917	-0.032	0.9711	0.8545	0.061	0.3662
4	-0.094	-0.0243	0.9695	0.9155	-0.1831	0.3052
5	-0.0907	-0.0273	0.9697	1.0986	-0.1831	0.4883
6	-0.0913	-0.026	0.9653	1.0376	-0.061	0.4883
7	-0.0919	-0.0243	0.9657	0.9766	-0.3052	0.1831
8	-0.0909	-0.0281	0.9696	0.9766	-0.061	0.6714
9	-0.0914	-0.0247	0.9674	1.0986	-0.1831	0.6714
10	-0.0909	-0.0272	0.9685	1.2817	-0.1221	0.6104
11	-0.0898	-0.0276	0.9678	1.1597	-0.061	0.7935
12	-0.0935	-0.0251	0.9692	1.1597	-0.061	0.6714
13	-0.09	-0.0282	0.9677	0.7935	-0.1221	0.4883
14	-0.0928	-0.0262	0.9683	1.0376	-0.3662	0.5493
15	-0.0922	-0.0261	0.9678	1.0376	0.0	0.4272
16	-0.0908	-0.0277	0.9685	0.9766	-0.2441	0.6104
17	-0.0922	-0.0253	0.9679	1.1597	-0.3052	0.6104
18	-0.0913	-0.028	0.9684	1.0376	-0.1221	0.6104
19	-0.0923	-0.0269	0.9684	1.0376	0.061	0.6104
20	-0.0918	-0.0256	0.9681	1.0376	-0.1831	0.6104

Figura 15: Datos obtenidos para una carencia de movimiento (estacionario).

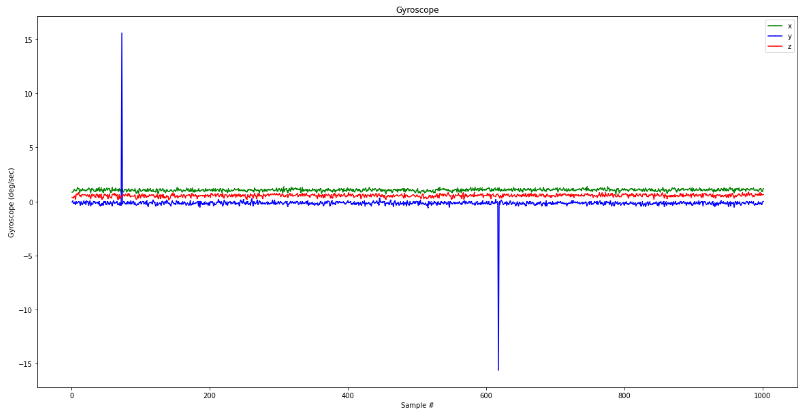


Figura 16: Gráfica de los datos obtenidos para una carencia de movimiento (estacionario).

Entrenamiento del modelo

A continuación se presentan las gráficas obtenidas durante el entrenamiento del modelo. Se puede notar en todas las gráficas que la tendencia o el comportamiento exhibido por los datos de validación (azul) son sumamente similares a la tendencia de los datos de los datos de entrenamiento (verde).

Error cuadrático medio del modelo

Las gráficas del error cuadrático medio tienen el objetivo de mostrar cuando deja de mejorar el modelo. Se puede notar que el modelo a nivel general deja de mejorar alrededor de la muestra 200, sin embargo se puede notar un comportamiento intermitente y periódico en la pérdida de la validación.

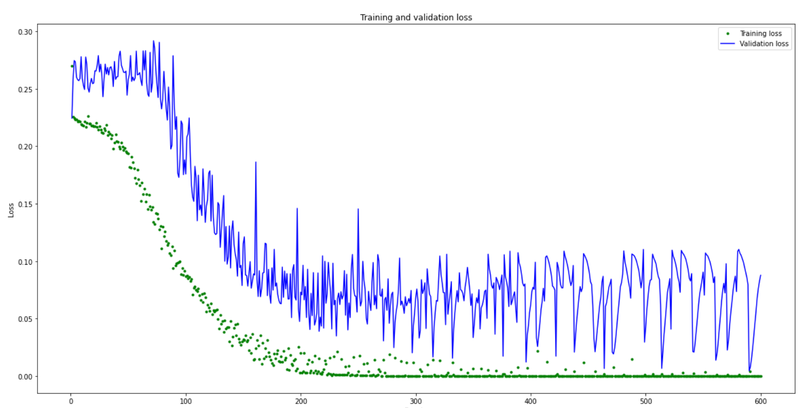


Figura 17: Error cuadrático medio del modelo.

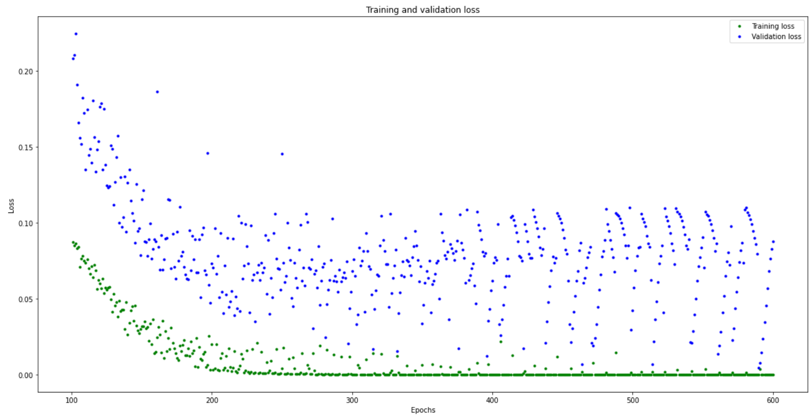


Figura 18: Error cuadrático medio del modelo, eliminando los primeros datos de la figura anterior.

Error absoluto medio del modelo

El error absoluto medio del modelo también se utiliza para evaluar su desempeño. Nótese que este alcanza valores bajos (10 %) y similares al del error cuadrático medio. Adicionalmente, el comportamiento periódico e intermitente observado en las gráficas anteriores también permanece presente.

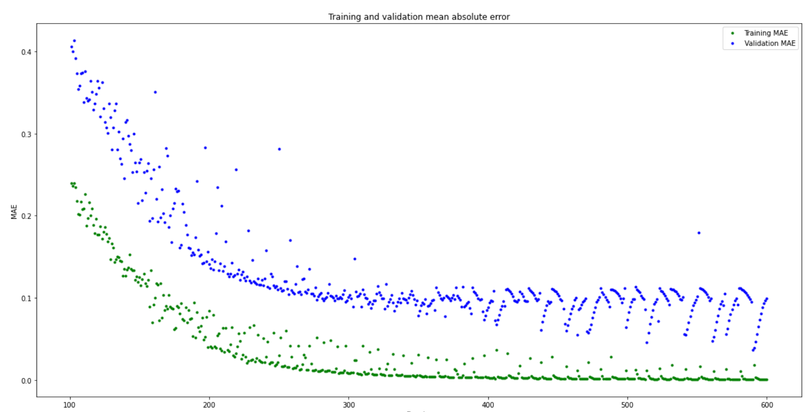


Figura 19: Error absoluto medio del modelo.

Ejecución con los datos de prueba

Luego se utilizan los datos de prueba del modelo para comparar con el entrenamiento realizado. La gráfica obtenida fue la siguiente:

Figura 20: Gráfica de los valores predichos por el modelo.

Resultados obtenidos a partir del modelo

Finalmente, una vez cargado el *firmware* con el modelo y ejecutándose el *script* para recolectar los resultados se obtuvo lo siguiente en la terminal:

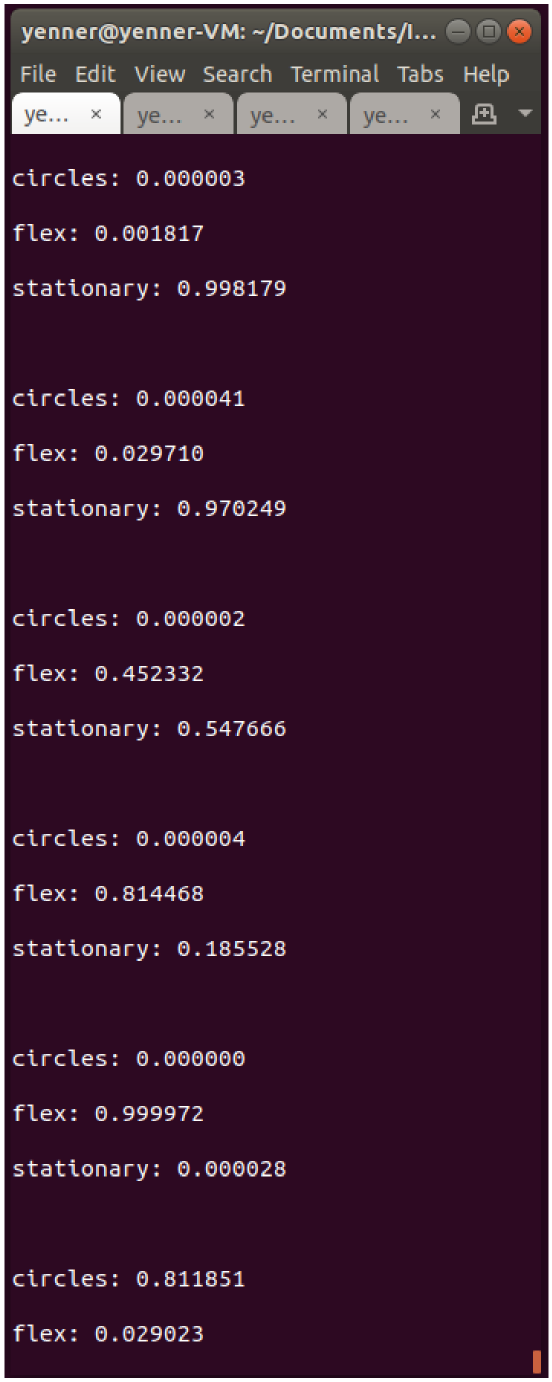


Figura 21: Resultados predichos por el modelo.

Nótese como los valores son altos en momentos distintos para cada movimiento, los primeros dos se interpretaron con certeza como estacionarios, el segundo no se tuvo certeza si fue estacionario o si fue una flexión, el cuarto se interpretó como una flexión y el último se consideró como un movimiento circular.

Estos resultados concuerdan generalmente con los movimientos realizados, los gestos estacionarios y de flexión son detectados adecuadamente la mayor parte del tiempo. Por su parte, los movimientos circulares sí se logran detectar en algunas ocasiones, mas en otras estos movimientos se interpretan como flexiones.

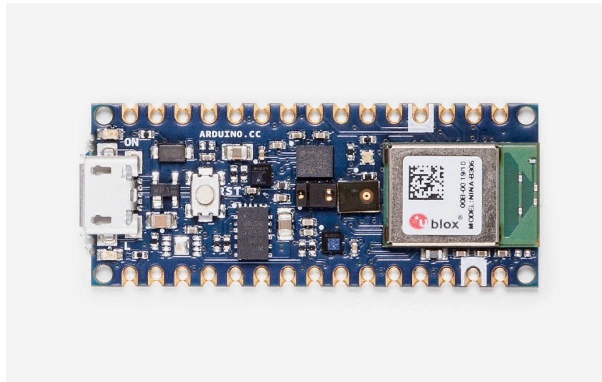
Conclusiones y recomendaciones

- Se logró utilizar el microcontrolador Arduino Nano 33 BLE para obtener datos de su acelerómetro/giroscopio y se enviaron dichos datos hacia la computadora mediante el puerto serial y un *script* de python.
- Se registraron 3 tipos distintos de movimientos que permitieron entrenar un modelo de TensorFlow Lite para detectar de qué clase de movimiento se trataba.
- El modelo obtenido presenta un desempeño aceptable, logrando identificar correctamente 2 de los 3 movimientos la mayor parte del tiempo (estacionario y flexión), mientras que los movimientos circulares no tienden a ser identificados como flexiones en algunas ocasiones.
- Se recomienda revisar que tanto el IDE como las conexiones funcionen adecuadamente antes de empezar a trabajar. Se tuvieron dificultades para cargar el *firmware* del microcontrolador utilizando una máquina virtual con Linux, por lo que fue necesario utilizar Windows para estos pasos (carga de *firmware*).

Apéndices

En esta sección se presentan las hojas del fabricante de los componentes utilizados.

Product Reference Manual
SKU: ABX00031



Description

Nano 33 BLE Sense is a miniature sized module containing a NINA B306 module, based on Nordic nRF52480 and containing a Cortex M4F, a crypto chip which can securely store certificates and pre shared keys and a 9 axis IMU. The module can either be mounted as a DIP component (when mounting pin headers), or as a SMT component, directly soldering it via the castellated pads

Target areas:

Maker, enhancements, IoT application

Features

- **NINA B306 Module**
    - **Processor**
        - 64 MHz Arm® Cortex-M4F (with FPU)
        - 1 MB Flash + 256 KB RAM
    - **Bluetooth® 5 multiprotocol radio**
        - 2 Mbps
        - CSA #2
        - Advertising Extensions
        - Long Range
        - +8 dBm TX power
        - -95 dBm sensitivity
        - 4.8 mA in TX (0 dBm)
        - 4.6 mA in RX (1 Mbps)
        - Integrated balun with 50 Ω single-ended output
        - IEEE 802.15.4 radio support
        - Thread
        - Zigbee
    - **Peripherals**
        - Full-speed 12 Mbps USB
        - NFC-A tag
        - Arm CryptoCell CC310 security subsystem
        - QSPI/SPI/TWI/I²S/PDM/QDEC
        - High speed 32 MHz SPI
        - Quad SPI interface 32 MHz
        - EasyDMA for all digital interfaces
        - 12-bit 200 ksps ADC
        - 128 bit AES/ECB/CCM/AAR co-processor
- **LSM9DS1** (9 axis IMU)
    - 3 acceleration channels, 3 angular rate channels, 3 magnetic field channels
    - ±2/±4/±8/±16 g linear acceleration full scale
    - ±4/±8/±12/±16 gauss magnetic full scale
    - ±245/±500/±2000 dps angular rate full scale
    - 16-bit data output
- **LPS22HB** (Barometer and temperature sensor)
    - 260 to 1260 hPa absolute pressure range with 24 bit precision
    - High overpressure capability: 20x full-scale
    - Embedded temperature compensation
    - 16-bit temperature data output
    - 1 Hz to 75 Hz output data rateInterrupt functions: Data Ready, FIFO flags, pressure thresholds
- **HTS221** (relative humidity sensor)
    - 0-100% relative humidity range
    - High rH sensitivity: 0.004% rH/LSB
    - Humidity accuracy: ± 3.5% rH, 20 to +80% rH
    - Temperature accuracy: ± 0.5 °C,15 to +40 °C
    - 16-bit humidity and temperature output data

- **APDS-9960** (Digital proximity, Ambient light, RGB and Gesture Sensor)
  - Ambient Light and RGB Color Sensing with UV and IR blocking filters
  - Very high sensitivity – Ideally suited for operation behind dark glass
  - Proximity Sensing with Ambient light rejection
  - Complex Gesture Sensing
- **MP34DT05** (Digital Microphone)
  - AOP = 122.5 dbSPL
  - 64 dB signal-to-noise ratio
  - Omnidirectional sensitivity
  - –26 dBFS ± 3 dB sensitivity
- **ATECC608A** (Crypto Chip)
  - Cryptographic co-processor with secure hardware based key storage
  - Protected storage for up to 16 keys, certificates or data
  - ECDH: FIPS SP800-56A Elliptic Curve Diffie-Hellman
  - NIST standard P256 elliptic curve support
  - SHA-256 & HMAC hash including off-chip context save/restore
  - AES-128 encrypt/decrypt, galois field multiply for GCM
- **MPM3610** DC-DC
  - Regulates input voltage from up to 21V with a minimum of 65% efficiency @minimum load
  - More than 85% efficiency @12V

Contents

1 The Board

As all Nano form factor boards, Nano 33 BLE Sense does not have a battery charger but can be powered through USB or headers.

NOTE: Arduino Nano 33 BLE Sense only supports 3.3V I/Os and is **NOT** 5V tolerant so please make sure you are not directly connecting 5V signals to this board or it will be damaged. Also, as opposed to Arduino Nano boards that support 5V operation, the 5V pin does NOT supply voltage but is rather connected, through a jumper, to the USB power input.

1.1 Ratings

1.1.1 Recommended Operating Conditions

Symbol	Description	Min	Max
	Conservative thermal limits for the whole board:	-40 °C (40 °F)	85°C (185 °F)

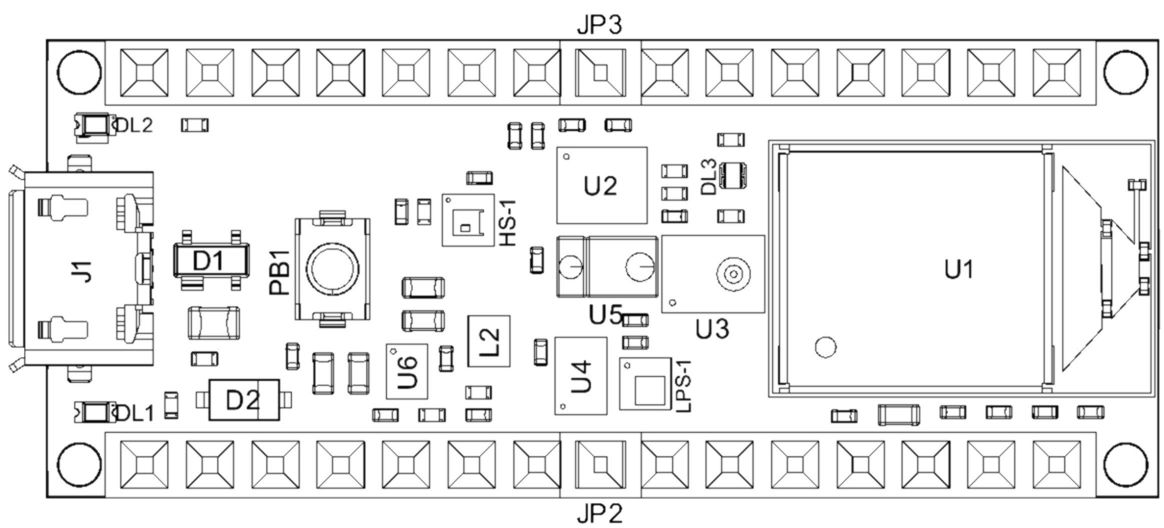
1.2 Power Consumption

Symbol	Description	Min	Typ	Max	Unit
PBL	Power consumption with busy loop		TBC		mW
PLP	Power consumption in low power mode		TBC		mW
PMAX	Maximum Power Consumption		TBC		mW

2 Functional Overview

2.1 Board Topology

Top:

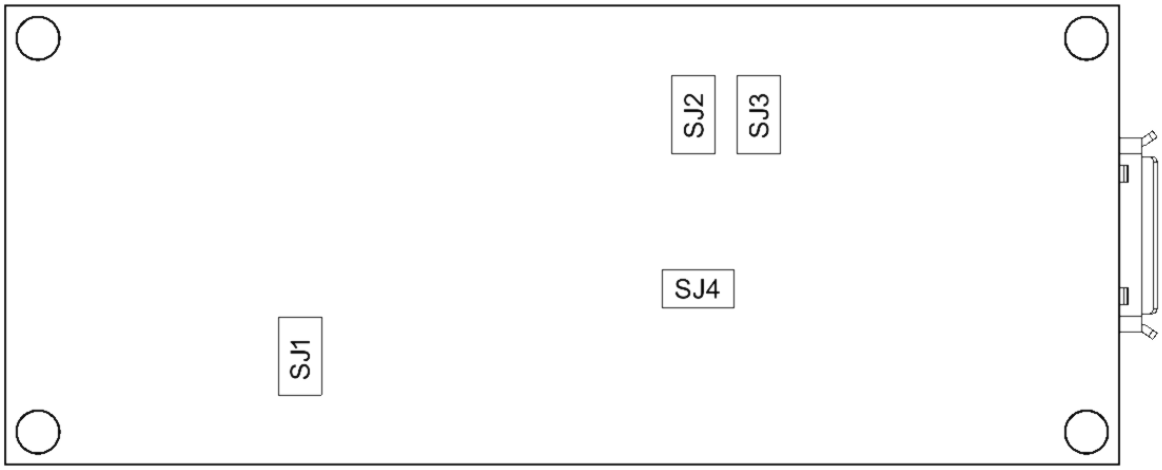


Board topology top

Ref.	Description	Ref.	Description
U1	NINA-B306 Module Bluetooth® Low Energy 5.0 Module	U6	MP2322GQH Step Down Converter
U2	LSM9DS1TR Sensor IMU	PB1	IT-1185AP1C-160G-GTR Push button
U3	MP34DT06JTR Mems Microphone	HS-1	HTS221 Humidity Sensor
U4	ATECC608A Crypto chip	DL1	Led L

Ref.	Description	Ref.	Description
U5	APDS-9660 Ambient Module	DL2	Led Power

Bottom:



Board topology bot

Ref.	Description	Ref.	Description
SJ1	VUSB Jumper	SJ2	D7 Jumper
SJ3	3v3 Jumper	SJ4	D8 Jumper

2.2 Processor

The Main Processor is a Cortex M4F running at up to 64MHz. Most of its pins are connected to the external headers, however some are reserved for internal communication with the wireless module and the on-board internal I^2C peripherals (IMU and Crypto).

NOTE: As opposed to other Arduino Nano boards, pins A4 and A5 have an internal pull up and default to be used as an I^2C Bus so usage as analog inputs is not recommended.

2.3 Crypto

The crypto chip in Arduino IoT boards is what makes the difference with other less secure boards as it provides a secure way to store secrets (such as certificates) and accelerates secure protocols while never exposing secrets in plain text.

Source code for the Arduino Library that supports the Crypto is available **[8]**

2.4 IMU

Arduino Nano 33 BLE has an embedded 9 axis IMU which can be used to measure board orientation (by checking the gravity acceleration vector orientation or by using the 3D compass) or to measure shocks, vibration, acceleration and rotation speed.

Source code for the Arduino Library that supports the IMU is available **[9]**

2.5 Barometer and Temperature Sensor

The embedded Barometer and temperature sensor allow measuring ambient pressure. The temperature sensor integrated with the barometer can be used to compensate the pressure measurement.

Source code for the Arduino Library that supports the Barometer is available **[10]**

2.6 Relative Humidity and Temperature Sensor

Relative humidity sensor measures ambient relative humidity. As the Barometer this sensor has an integrated temperature sensor that can be used to compensate for the measurement.

Source code for the Arduino Library that supports the Humidity sensor is available **[11]**

2.7 Digital Proximity, Ambient Light, RGB and Gesture Sensor

Source code for the Arduino Library that supports the Proximity/gesture/ALS sensor is available **[12]**

2.7.1 Gesture Detection

Gesture detection utilizes four directional photodiodes to sense reflected IR energy (sourced by the integrated LED) to convert physical motion information (i.e. velocity, direction and distance) to a digital information. The architecture of the gesture engine features automatic activation (based on Proximity engine results), ambient light subtraction, cross-talk cancellation, dual 8-bit data converters, power saving inter-conversion delay, 32-dataset FIFO, and interrupt driven I2C communication. The gesture engine accommodates a wide range of mobile device gesturing requirements: simple UP-DOWN-RIGHT-LEFT gestures or more complex gestures can be accurately sensed. Power consumption and noise are minimized with adjustable IR LED timing.

2.7.2 Proximity Detection

The Proximity detection feature provides distance measurement (E.g. mobile device screen to user’s ear) by photodiode detection of reflected IR energy (sourced by the integrated LED). Detect/release events are interrupt driven, and occur whenever proximity result crosses upper and/ or lower threshold settings. The proximity engine features offset adjustment registers to compensate for system offset caused by unwanted IR energy reflections appearing at the sensor. The IR LED intensity is factory trimmed to eliminate the need for end-equipment calibration due to component variations. Proximity results are further improved by automatic ambient light subtraction.

2.7.3 Color and ALS Detection

The Color and ALS detection feature provides red, green, blue and clear light intensity data. Each of the R, G, B, C channels have a UV and IR blocking filter and a dedicated data converter producing16-bit data simultaneously. This architecture allows applications to accurately measure ambient light and sense color which enables devices to calculate color temperature and control display backlight.

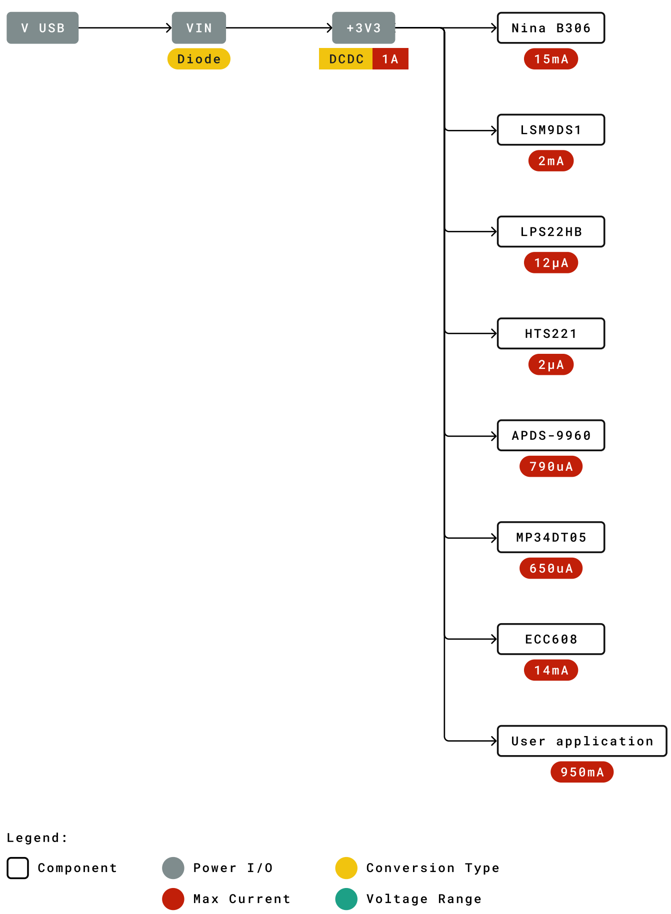
2.8 Digital Microphone

The MP34DT05 is an ultra-compact, low-power, omnidirectional, digital MEMS microphone built with a capacitive sensing element and an IC interface.

The sensing element, capable of detecting acoustic waves, is manufactured using a specialized silicon micromachining process dedicated to produce audio sensors

2.9 Power Tree

The board can be powered via USB connector, V_{IN} or V_{USB} pins on headers.



Power tree

NOTE: Since V_{USB} feeds V_{IN} via a Schottky diode and a DC-DC regulator specified minimum input voltage is 4.5V the minimum supply voltage from USB has to be increased to a voltage in the range between 4.8V to 4.96V depending on the current being drawn.

3 Board Operation

3.1 Getting Started - IDE

If you want to program your Arduino Nano 33 BLE while offline you need to install the Arduino Desktop IDE [1] To connect the Arduino Nano 33 BLE to your computer, you'll need a Micro-B USB cable. This also provides power to the board, as indicated by the LED.

3.2 Getting Started - Arduino Web Editor

All Arduino boards, including this one, work out-of-the-box on the Arduino Web Editor [2], by just installing a simple plugin.

The Arduino Web Editor is hosted online, therefore it will always be up-to-date with the latest features and support for all boards. Follow **[3]** to start coding on the browser and upload your sketches onto your board.

3.3 Getting Started - Arduino IoT Cloud

All Arduino IoT enabled products are supported on Arduino IoT Cloud which allows you to Log, graph and analyze sensor data, trigger events, and automate your home or business.

3.4 Sample Sketches

Sample sketches for the Arduino Nano 33 BLE can be found either in the "Examples" menu in the Arduino IDE or in the "Documentation" section of the Arduino Pro website [4]

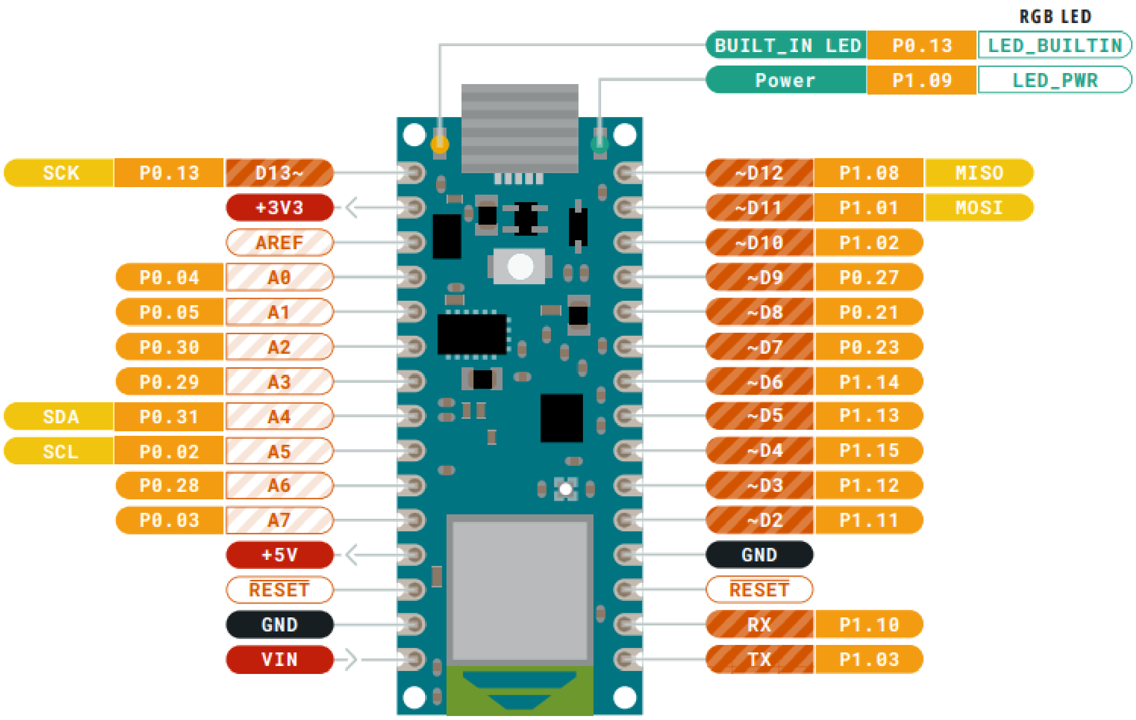
3.5 Online Resources

Now that you have gone through the basics of what you can do with the board you can explore the endless possibilities it provides by checking exciting projects on ProjectHub **[13]**, the Arduino Library Reference **[14]** and the on line store **[15]** where you will be able to complement your board with sensors, actuators and more.

3.6 Board Recovery

All Arduino boards have a built-in bootloader which allows flashing the board via USB. In case a sketch locks up the processor and the board is not reachable anymore via USB it is possible to enter bootloader mode by double-tapping the reset button right after power up.

4 Connector Pinouts



Pinout

4.1 USB

Pin	Function	Type	Description
1	VUSB	Power	Power Supply Input. If board is powered via VUSB from header this is an Output **(1)**
2	D-	Differential	USB differential data -
3	D+	Differential	USB differential data +
4	ID	Analog	Selects Host/Device functionality
5	GND	Power	Power Ground

4.2 Headers

The board exposes two 15 pin connectors which can either be assembled with pin headers or soldered through castellated vias.

Pin	Function	Type	Description
1	D13	Digital	GPIO
2	+3V3	Power Out	Internally generated power output to external devices
3	AREF	Analog	Analog Reference; can be used as GPIO
4	A0/DAC0	Analog	ADC in/DAC out; can be used as GPIO
5	A1	Analog	ADC in; can be used as GPIO
6	A2	Analog	ADC in; can be used as GPIO
7	A3	Analog	ADC in; can be used as GPIO
8	A4/SDA	Analog	ADC in; I2C SDA; Can be used as GPIO **(1)**
9	A5/SCL	Analog	ADC in; I2C SCL; Can be used as GPIO **(1)**
10	A6	Analog	ADC in; can be used as GPIO
11	A7	Analog	ADC in; can be used as GPIO
12	VUSB	Power In/Out	Normally NC; can be connected to VUSB pin of the USB connector by shorting a jumper
13	RST	Digital In	Active low reset input (duplicate of pin 18)
14	GND	Power	Power Ground

Pin	Function	Type	Description
15	VIN	Power In	Vin Power input
16	TX	Digital	USART TX; can be used as GPIO
17	RX	Digital	USART RX; can be used as GPIO
18	RST	Digital	Active low reset input (duplicate of pin 13)
19	GND	Power	Power Ground
20	D2	Digital	GPIO
21	D3/PWM	Digital	GPIO; can be used as PWM
22	D4	Digital	GPIO
23	D5/PWM	Digital	GPIO; can be used as PWM
24	D6/PWM	Digital	GPIO, can be used as PWM
25	D7	Digital	GPIO
26	D8	Digital	GPIO
27	D9/PWM	Digital	GPIO; can be used as PWM
28	D10/PWM	Digital	GPIO; can be used as PWM
29	D11/MOSI	Digital	SPI MOSI; can be used as GPIO
30	D12/MISO	Digital	SPI MISO; can be used as GPIO

4.3 Debug

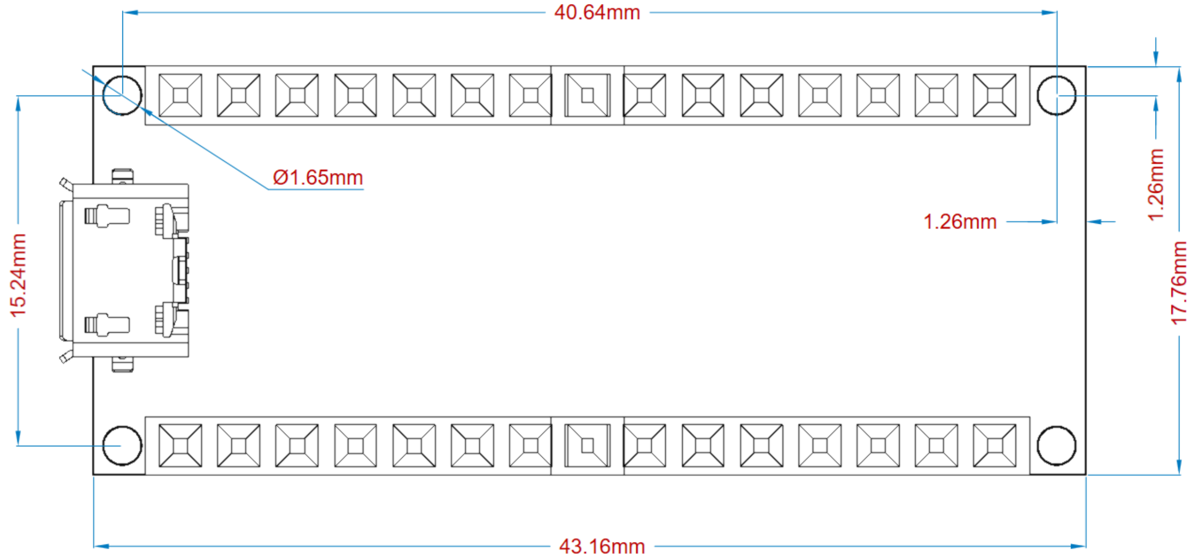
On the bottom side of the board, under the communication module, debug signals are arranged as 3x2 test pads with 100 mil pitch with pin 4 removed. Pin 1 is depicted in Figure 3 – Connector Positions

Pin	Function	Type	Description
1	+3V3	Power Out	Internally generated power output to be used as voltage reference
2	SWD	Digital	nRF52480 Single Wire Debug Data
3	SWCLK	Digital In	nRF52480 Single Wire Debug Clock
5	GND	Power	Power Ground
6	RST	Digital In	Active low reset input

5 Mechanical Information

5.1 Board Outline and Mounting Holes

The board measures are mixed between metric and imperial. Imperial measures are used to maintain 100 mil pitch grid between pin rows to allow them to fit a breadboard whereas board length is Metric



Board layout

6 Certifications

6.1 Declaration of Conformity CE DoC (EU)

We declare under our sole responsibility that the products above are in conformity with the essential requirements of the following EU Directives and therefore qualify for free movement within markets comprising the European Union (EU) and European Economic Area (EEA).

6.2 Declaration of Conformity to EU RoHS & REACH 211 01/19/2021

Arduino boards are in compliance with RoHS 2 Directive 2011/65/EU of the European Parliament and RoHS 3 Directive 2015/863/EU of the Council of 4 June 2015 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

Substance	Maximum limit (ppm)
Lead (Pb)	1000
Cadmium (Cd)	100
Mercury (Hg)	1000
Hexavalent Chromium (Cr6+)	1000
Poly Brominated Biphenyls (PBB)	1000
Poly Brominated Diphenyl ethers (PBDE)	1000
Bis(2-Ethylhexyl} phthalate (DEHP)	1000
Benzyl butyl phthalate (BBP)	1000
Dibutyl phthalate (DBP)	1000
Diisobutyl phthalate (DIBP)	1000

Exemptions : No exemptions are claimed.

Arduino Boards are fully compliant with the related requirements of European Union Regulation (EC) 1907 /2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH). We declare none of the SVHCs (https://echa.europa.eu/web/guest/candidate-list-table), the Candidate List of Substances of Very High Concern for authorization currently released by ECHA, is present in all products (and also package) in quantities totaling in a concentration equal or above 0.1%. To the best of our knowledge, we also declare that our products do not contain any of the substances listed on the "Authorization List"

(Annex XIV of the REACH regulations) and Substances of Very High Concern (SVHC) in any significant amounts as specified by the Annex XVII of Candidate list published by ECHA (European Chemical Agency) 1907 /2006/EC.

6.3 Conflict Minerals Declaration

As a global supplier of electronic and electrical components, Arduino is aware of our obligations with regards to laws and regulations regarding Conflict Minerals, specifically the Dodd-Frank Wall Street Reform and Consumer Protection Act, Section 1502. Arduino does not directly source or process conflict minerals such as Tin, Tantalum, Tungsten, or Gold. Conflict minerals are contained in our products in the form of solder, or as a component in metal alloys. As part of our reasonable due diligence Arduino has contacted component suppliers within our supply chain to verify their continued compliance with the regulations. Based on the information received thus far we declare that our products contain Conflict Minerals sourced from conflict-free areas.

7 FCC Caution

Any Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions:

(1) This device may not cause harmful interference

(2) this device must accept any interference received, including interference that may cause undesired operation.

FCC RF Radiation Exposure Statement:

1. This Transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.
2. This equipment complies with RF radiation exposure limits set forth for an uncontrolled environment.
3. This equipment should be installed and operated with minimum distance 20cm between the radiator & your body.

English: User manuals for license-exempt radio apparatus shall contain the following or equivalent notice in a conspicuous location in the user manual or alternatively on the device or both. This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions:

(1) this device may not cause interference

(2) this device must accept any interference, including interference that may cause undesired operation of the device.

French: Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes :

(1) l' appareil nedoit pas produire de brouillage

(2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

IC SAR Warning:

English This equipment should be installed and operated with minimum distance 20 cm between the radiator and your body.

French: Lors de l' installation et de l' exploitation de ce dispositif, la distance entre le radiateur et le corps est d 'au moins 20 cm.

Important: The operating temperature of the EUT can't exceed 85℃ and shouldn't be lower than -40℃.

Hereby, Arduino S.r.l. declares that this product is in compliance with essential requirements and other relevant provisions of Directive 2014/53/EU. This product is allowed to be used in all EU member states.

Frequency bands	Maximum output power (ERP)
863-870Mhz	5.47 dBm

8 Company Information

Company name	Arduino S.r.l
Company Address	Via Andrea Appiani 25 20900 MONZA Italy

9 Reference Documentation

Reference	Link
Arduino IDE (Desktop)	https://www.arduino.cc/en/software
Arduino IDE (Cloud)	https://create.arduino.cc/editor
Cloud IDE Getting Started	https://create.arduino.cc/projecthub/Arduino_Genuino/getting-started-with-arduino-web-editor-4b3e4a
Forum	http://forum.arduino.cc/
Nina B306	https://content.u-blox.com/sites/default/files/NINA-B3_DataSheet_UBX-17052099.pdf
ECC608	https://ww1.microchip.com/downloads/aemDocuments/documents/SCBU/ProductDocuments/DataSheets/ATECC608A-CryptoAuthentication-Device-Summary-Data-Sheet-DS40001977B.pdf
MPM3610	https://www.monolithicpower.com/pub/media/document/MPM3610_r1.01.pdf
ECC608 Library	https://github.com/arduino-libraries/ArduinoECCX08
LSM6DSL Library	https://github.com/adafruit/Adafruit_LSM9DS1
LPS22HB	https://github.com/stm32duino/LPS22HB
HTS221 Library	https://github.com/stm32duino/HTS221
APDS9960 Library	https://github.com/adafruit/Adafruit_APDS9960
ProjectHub	https://create.arduino.cc/projecthub?by=part&part_id=11332&sort=trending
Library Reference	https://www.arduino.cc/reference/en/

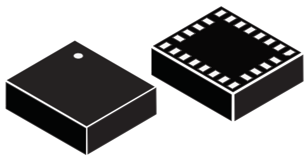
10 Revision History

Date	Revision	Changes
08/03/2022	2	Reference documentation links updates
04/27/2021	1	General datasheet updates

LSM9DS1

iNEMO inertial module: 3D accelerometer, 3D gyroscope, 3D magnetometer

Datasheet - production data



LGA-24L (3.5x3x1.0 mm)

Features

- 3 acceleration channels, 3 angular rate channels, 3 magnetic field channels
- ±2/±4/±8/±16 *g* linear acceleration full scale
- ±4/±8/±12/±16 gauss magnetic full scale
- ±245/±500/±2000 dps angular rate full scale
- 16-bit data output
- SPI / I^2C serial interfaces
- Analog supply voltage 1.9 V to 3.6 V
- “Always-on” eco power mode down to 1.9 mA
- Programmable interrupt generators
- Embedded temperature sensor
- Embedded FIFO
- Position and motion detection functions
- Click/double-click recognition
- Intelligent power saving for handheld devices
- ECOPACK®, RoHS and “Green” compliant

Applications

- Indoor navigation
- Smart user interfaces
- Advanced gesture recognition
- Gaming and virtual reality input devices
- Display/map orientation and browsing

Description

The LSM9DS1 is a system-in-package featuring a 3D digital linear acceleration sensor, a 3D digital angular rate sensor, and a 3D digital magnetic sensor.

The LSM9DS1 has a linear acceleration full scale of ±2*g*/±4*g*/±8/±16 *g,* a magnetic field full scale of ±4/±8/±12/±16 gauss and an angular rate of ±245/±500/±2000 dps.

The LSM9DS1 includes an I^2C serial bus interface supporting standard and fast mode (100 kHz and 400 kHz) and an SPI serial standard interface.

Magnetic, accelerometer and gyroscope sensing can be enabled or set in power-down mode separately for smart power management.

The LSM9DS1 is available in a plastic land grid array package (LGA) and it is guaranteed to operate over an extended temperature range from -40 °C to +85 °C.

Table 1. Device summary

Part number	Temperature range [°C]	Package	Packing
LSM9DS1	-40 to +85	LGA-24L	Tray
LSM9DS1TR	-40 to +85	LGA-24L	Tape and reel

1 Pin description

Figure 1. Pin connections

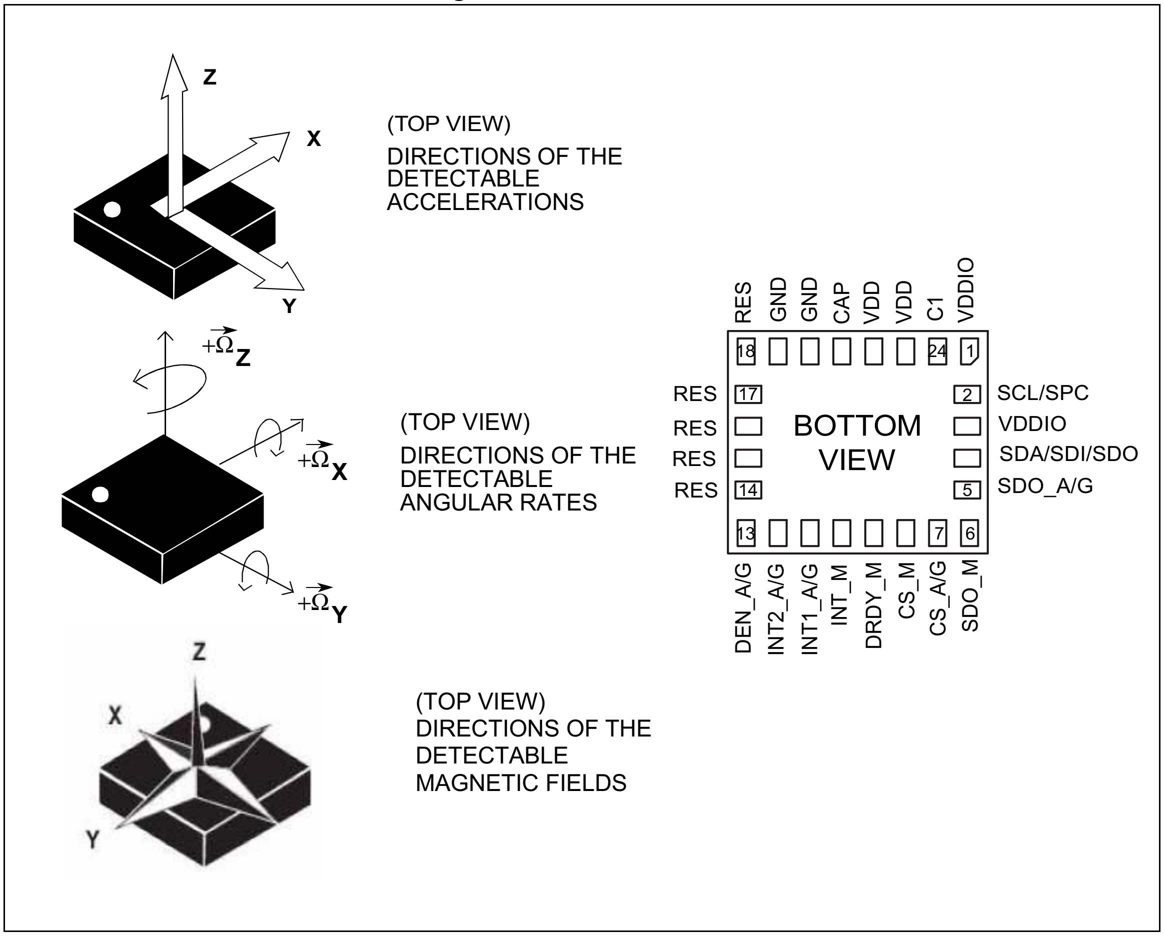


Table 2. Pin description

Pin #	Name	Function
1	VDDIO(1)	Power supply for I/O pins
2	SCL/SPC	I^2C serial clock (SCL) / SPI serial port clock (SPC)
3	VDDIO(2)	Power supply for I/O pins
4	SDA/SDI/SDO	I^2C serial data (SDA) SPI serial data input (SDI) 3-wire interface serial data output (SDO)
5	SDO_A/G	SPI serial data output (SDO) for the accelerometer and gyroscope I^2C least significant bit of the device address (SA0) for the accelerometer and gyroscope
6	SDO_M	SPI serial data output (SDO) for the magnetometer I^2C least significant bit of the device address (SA0) for the magnetometer
7	CS_A/G	SPI enable I^2C/SPI mode selection for the accelerometer and gyroscope (1: SPI idle mode / I^2C communication enabled; 0: SPI communication mode / I^2C disabled)
8	CS_M	SPI enable I^2C/SPI mode selection for the magnetometer (1: SPI idle mode / I^2C communication enabled; 0: SPI communication mode / I^2C disabled)
9	DRDY_M	Magnetic sensor data ready
10	INT_M	Magnetic sensor interrupt
11	INT1_A/G	Accelerometer and gyroscope interrupt 1
12	INT2_A/G	Accelerometer and gyroscope interrupt 2
13	DEN_A/G	Accelerometer and gyroscope data enable
14	RES	Reserved. Connected to GND.
15	RES	Reserved. Connected to GND.
16	RES	Reserved. Connected to GND.
17	RES	Reserved. Connected to GND.
18	RES	Reserved. Connected to GND.
19	GND	0 V supply
20	GND	0 V supply
21	CAP	Connected to GND with ceramic capacitor(3)
22	VDD(4)	Power supply
23	VDD(5)	Power supply
24	C1	Capacitor connection (C1 = 100 nF)

1. Recommended 100 nF filter capacitor.
2. Recommended 100 nF filter capacitor.
3. 10 nF (±10%), 16 V. 1 nF minimum value has to be guaranteed under 11 V bias condition.
4. Recommended 100 nF plus 10 µF capacitors.
5. Recommended 100 nF plus 10 µF capacitors.

2 Module specifications

2.1 Sensor characteristics

@ Vdd = 2.2 V, T = 25 °C unless otherwise noted[a]

Table 3. Sensor characteristics

Symbol	Parameter	Test conditions	Min.	Typ.[1]	Max.	Unit
LA_FS	Linear acceleration measurement range			±2		*g*
				±4		
				±8		
				±16		
M_FS	Magnetic measurement range			±4		gauss
				±8		
				±12		
				±16		
G_FS	Angular rate measurement range			±245		dps
				±500		
				±2000		
LA_So	Linear acceleration sensitivity	Linear acceleration FS = ±2 *g*		0.061		m*g*/LSB
		Linear acceleration FS = ±4 *g*		0.122		
		Linear acceleration FS = ±8 *g*		0.244		
		Linear acceleration FS = ±16 *g*		0.732		
M_GN	Magnetic sensitivity	Magnetic FS = ±4 gauss		0.14		mgauss/ LSB
		Magnetic FS = ±8 gauss		0.29		
		Magnetic FS = ±12 gauss		0.43		
		Magnetic FS = ±16 gauss		0.58		
G_So	Angular rate sensitivity	Angular rate FS = ±245 dps		8.75		mdps/ LSB
		Angular rate FS = ±500 dps		17.50		
		Angular rate FS = ±2000 dps		70		
LA_TyOff	Linear acceleration typical zero-g level offset accuracy[2]	FS = ±8 *g*		±90		m*g*
M_TyOff	Zero-gauss level [3]	FS = ±4 gauss		±1		gauss
G_TyOff	Angular rate typical zero-rate level [4]	FS = ±2000 dps		±30		dps
M_DF	Magnetic disturbance field	Zero-gauss offset starts to degrade			50	gauss
Top	Operating temperature range		-40		+85	°C

1. Typical specifications are not guaranteed
2. Typical zero-*g* level offset value after soldering
3. Typical zero-gauss level value after test and trimming
4. Typical zero rate level offset value after MSL3 preconditioning

a. The product is factory calibrated at 2.2 V. The operational power supply range is from 1.9 V to 3.6 V.

2.2 Electrical characteristics

@ Vdd = 2.2 V, T = 25 °C unless otherwise noted[b]

Table 4. Electrical characteristics

Symbol	Parameter	Test conditions	Min.	Typ.[1]	Max.	Unit
Vdd	Supply voltage		1.9		3.6	V
Vdd_IO	Module power supply for I/O		1.71		Vdd+0.1	
Idd_XM	Current consumption of the accelerometer and magnetic sensor in normal mode [2]			600		µA
Idd_G	Gyroscope current consumption in normal mode[3]			4.0		mA
Top	Operating temperature range		-40		+85	°C
Trise	Time for power supply rising[4]		0.01		100	ms
Twait	Time delay between Vdd_IO and Vdd[4]		0		10	ms

1. Typical specifications are not guaranteed
2. Magnetic sensor in high-resolution mode (ODR = 20 Hz), accelerometer sensor in normal mode, gyroscope in power-down mode
3. Accelerometer and magnetic sensor in power-down mode
4. Please refer to *Section 2.2.1: Recommended power-up sequence* for more details.

b. LSM9DS1 is factory calibrated at 2.2 V.

2.6 Terminology

2.6.1 Sensitivity

Linear acceleration sensitivity can be determined, for example, by applying 1 *g* acceleration to the device. Because the sensor can measure DC accelerations, this can be done easily by pointing the selected axis towards the ground, noting the output value, rotating the sensor 180 degrees (pointing towards the sky) and noting the output value again. By doing so, ±1 *g* acceleration is applied to the sensor. Subtracting the larger output value from the smaller one, and dividing the result by 2, leads to the actual sensitivity of the sensor. This value changes very little over temperature and over time. The sensitivity tolerance describes the range of sensitivities of a large number of sensors.

An angular rate gyroscope is device that produces a positive-going digital output for counterclockwise rotation around the axis considered. Sensitivity describes the gain of the sensor and can be determined by applying a defined angular velocity to it. This value changes very little over temperature and time.

Magnetic sensor sensitivity describes the gain of the sensor and can be determined, for example, by applying a magnetic field of 1 *gauss* to it.

2.6.2 Zero-*g*, zero-rate and zero-*gauss* level

Linear acceleration zero-*g* level offset (TyOff) describes the deviation of an actual output signal from the ideal output signal if no acceleration is present. A sensor in a steady state on a horizontal surface will measure 0 *g* on both the X-axis and Y-axis, whereas the Z-axis will measure 1 *g*. Ideally, the output is in the middle of the dynamic range of the sensor (content of OUT registers 00h, data expressed as two's complement number). A deviation from the ideal value in this case is called zero-*g* offset.

Offset is to some extent a result of stress to MEMS sensor and therefore the offset can slightly change after mounting the sensor onto a printed circuit board or exposing it to extensive mechanical stress. Offset changes little over temperature, see "Linear acceleration zero-*g* level change vs. temperature" in *Table 3*. The zero-*g* level tolerance (TyOff) describes the standard deviation of the range of zero-*g* levels of a group of sensors.

Zero-rate level describes the actual output signal if there is no angular rate present. The zero-rate level of precise MEMS sensors is, to some extent, a result of stress to the sensor and therefore the zero-rate level can slightly change after mounting the sensor onto a printed circuit board or after exposing it to extensive mechanical stress. This value changes very little over temperature and time.

Zero-*g*auss level offset (M_TyOff) describes the deviation of an actual output signal from the ideal output if no magnetic field is present.

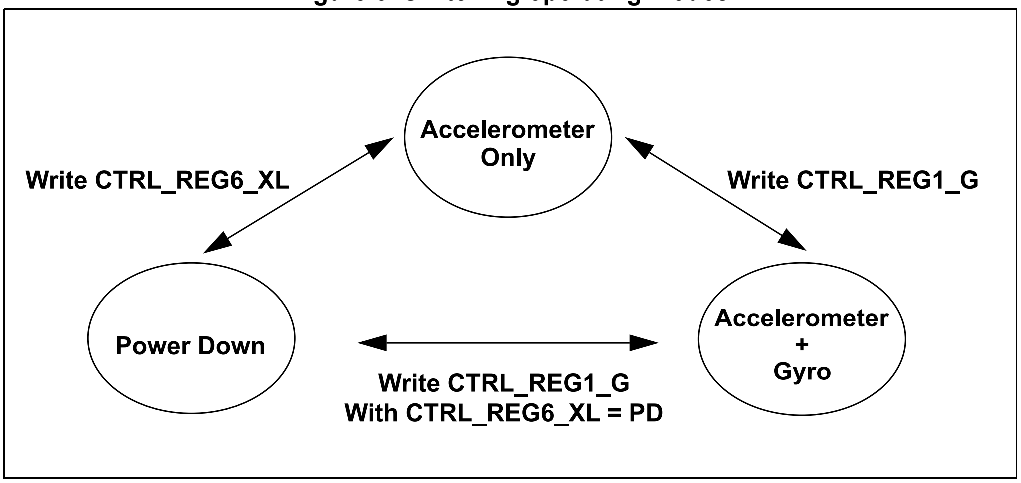
3 LSM9DS1 functionality

3.1 Operating modes

In the LSM9DS1 the accelerometer and gyroscope have two operating modes available: only accelerometer active and gyroscope in power down or both accelerometer and gyroscope sensors active at the same ODR. Switching from one mode to the other requires one write operation: writing to *CTRL_REG6_XL (20h)*, the accelerometer operates in normal mode and the gyroscope is powered down, writing to *CTRL_REG1_G (10h)* both accelerometer and gyroscope are activated at the same ODR.

Figure 5 depicts both modes of operation from power down.

Figure 5. Switching operating modes



The magnetic sensor has three operating modes available: power-down (default), continuous-conversion mode and single-conversion mode. Switching from power-down to the other modes requires one write operation to *CTRL_REG3_M (22h)*, setting values in the MD[1:0] bits. For the output of the magnetic data compensated by temperature, the TEMP_COMP bit in *CTRL_REG1_M (20h)* must be set to '1'.

3.2 Gyroscope power modes

In the LSM9DS1, the gyroscope can be configured in three different operating modes: power-down, low-power and normal mode.

Low-power mode is available for lower ODR (14.9, 59.5, 119 Hz) while for greater ODR (238, 476, 952 Hz) the device is automatically in normal mode. *Table* summarizes the ODR configuration (ODR_G[2:0] bits set in *CTRL_REG1_G (10h)*) and corresponding power modes.

To enable low-power mode, the LP_mode bit in *CTRL_REG3_G (12h)* has to be set to '1'.

Low-power mode allows reaching low power consumption while maintaining the device always on, refer to *Table 10*.

Table 9. Gyroscope operating modes

ODR_G [2:0]	ODR [Hz]	Power mode
000	Power down	Power-down
001	14.9	Low-power/Normal mode
010	59.5	Low-power/Normal mode
011	119	Low-power/Normal mode
100	238	Normal mode
101	476	Normal mode
110	952	Normal mode

Table 10. Operating mode current consumption

ODR [Hz]	Power mode	Current consumption(1) [mA]
14.9	Low-power	1.9
59.5	Low-power	2.4
119	Low-power	3.1
238	Normal mode	4.3
476	Normal mode	4.3
952	Normal mode	4.3

1. Typical values of gyroscope and accelerometer current consumption are based on characterization data.

Table 11. Accelerometer turn-on time

ODR [Hz]	BW = 400 Hz(1)	BW = 200 Hz(1)	BW = 100 Hz(1)	BW = 50 Hz(1)
14.9	0	0	0	0
59.5	0	0	0	0
119	1	1	1	2
238	1	1	2	4
476	1	2	4	7
952	2	4	7	14

1. The table contains the number of samples to be discarded after switching between power-down mode and normal mode.

Table 12. Gyroscope turn-on time

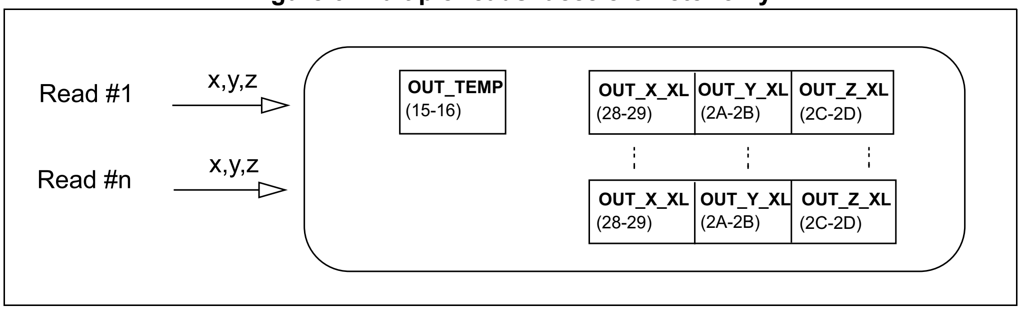
ODR [Hz]	LPF1 only(1)	LPF1 and LPF2(1)
14.9	2	LPF2 not available
59.5 or 119	3	13
238	4	14
476	5	15
952	8	18

1. The table contains the number of samples to be discarded after switching between low-power mode and normal mode.

3.3 Accelerometer and gyroscope multiple reads (burst)

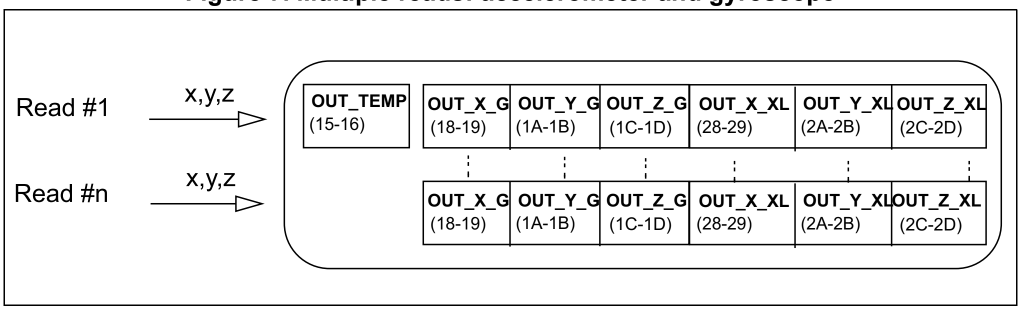
When only accelerometer is activated and the gyroscope is in power down, starting from *OUT_X_XL (28h - 29h)* multiple reads can be performed. Once *OUT_Z_XL (2Ch - 2Dh)* is read, the system automatically restarts from *OUT_X_XL (28h - 29h)* (see *Figure 6*).

Figure 6. Multiple reads: accelerometer only



When both accelerometer and gyroscope sensors are activated at the same ODR, starting from *OUT_X_G (18h - 19h)* multiple reads can be performed. Once *OUT_Z_XL (2Ch - 2Dh)* is read, the system automatically restarts from *OUT_X_G (18h - 19h)* (see *Figure 7*).

Figure 7. Multiple reads: accelerometer and gyroscope



3.4 Block diagram

Figure 8. Accelerometer and gyroscope digital block diagram

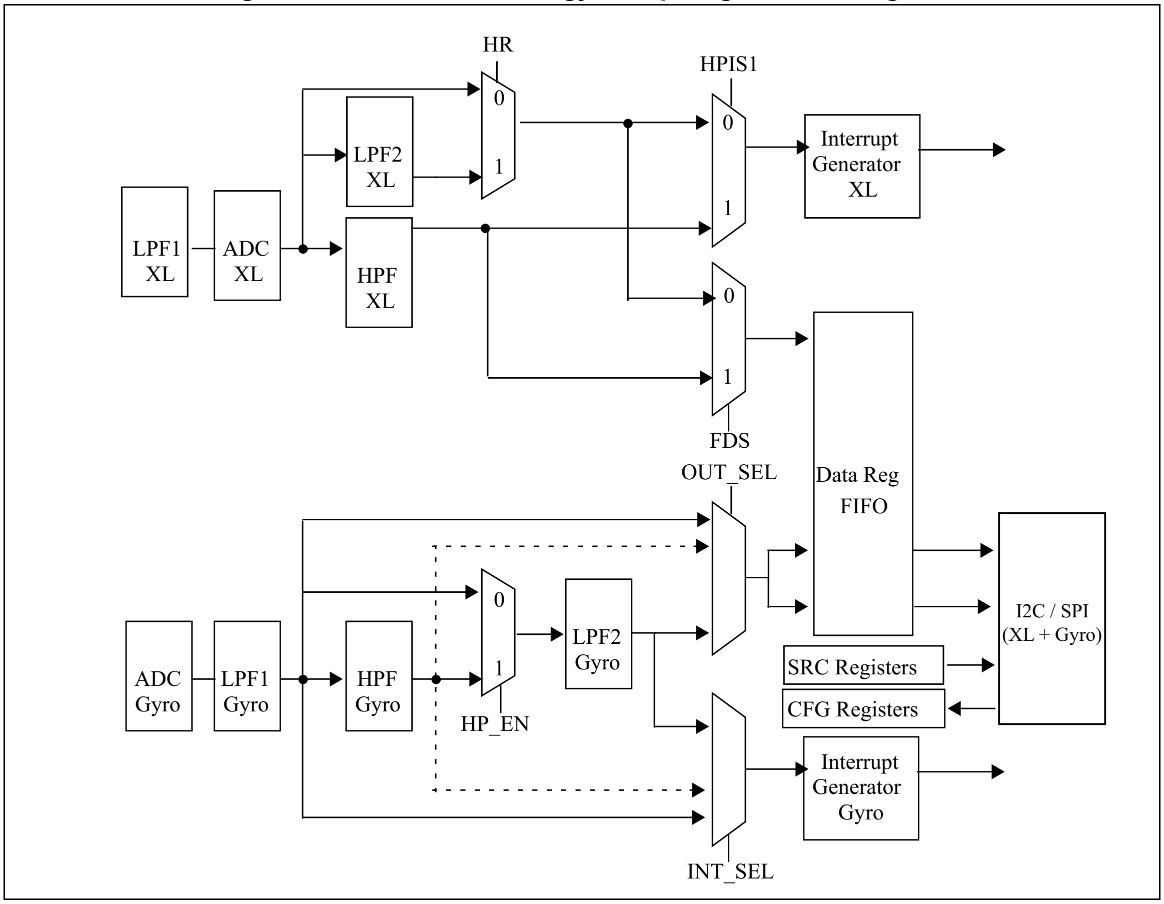
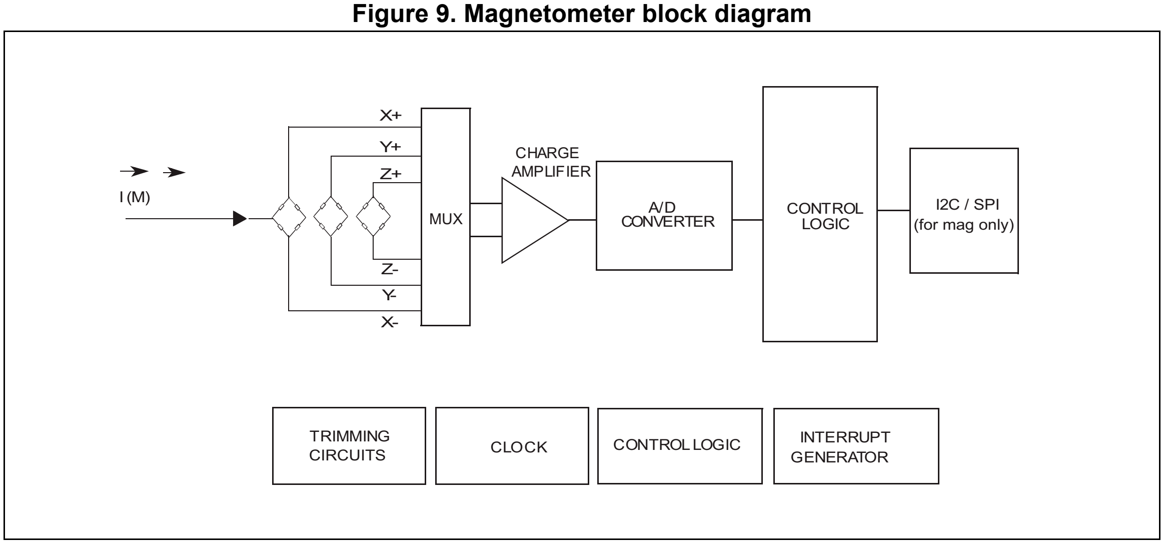


Figure 9. Magnetometer block diagram



3.5 Accelerometer and gyroscope FIFO

The LSM9DS1 embeds 32 slots of 16-bit data FIFO for each of the gyroscope's three output channels, yaw, pitch and roll, and 16-bit data FIFO for each of the accelerometer's three output channels, X, Y and Z. This allows consistent power saving for the system since the host processor does not need to continuously poll data from the sensor, but it can wake up only when needed and burst the significant data out from the FIFO. This buffer can work accordingly to five different modes: Bypass mode, FIFO-mode, Continuous mode, Continuous-to-FIFO mode and Bypass-to-Continuous. Each mode is selected by the FMODE [2:0] bits in the *FIFO_CTRL (2Eh)* register. Programmable FIFO threshold status, FIFO overrun events and the number of unread samples stored are available in the *FIFO_SRC (2Fh)* register and can be set to generate dedicated interrupts on the INT1_A/G pin in the *INT1_CTRL (0Ch)* register and on the INT2_A/G pin in the *INT2_CTRL (0Dh)* register.

FIFO_SRC (2Fh)(FTH) goes to '1' when the number of unread samples (*FIFO_SRC (2Fh)* (FSS5:0)) is greater than or equal to FTH [4:0] in *FIFO_CTRL (2Eh)*. If *FIFO_CTRL (2Eh)* (FTH[4:0]) is equal to 0, *FIFO_SRC (2Fh)*(FTH) goes to '0'.

FIFO_SRC (2Fh)(OVRN) is equal to '1' if a FIFO slot is overwritten.

FIFO_SRC (2Fh)(FSS [5:0]) contains stored data levels of unread samples. When FSS [5:0] is equal to '000000' FIFO is empty, when FSS [5:0] is equal to '100000' FIFO is full and the unread samples are 32.

The FIFO feature is enabled by writing '1' in *CTRL_REG9 (23h)* (FIFO_EN).

To guarantee the correct acquisition of data during the switching into and out of FIFO mode, the first sample acquired must be discarded.

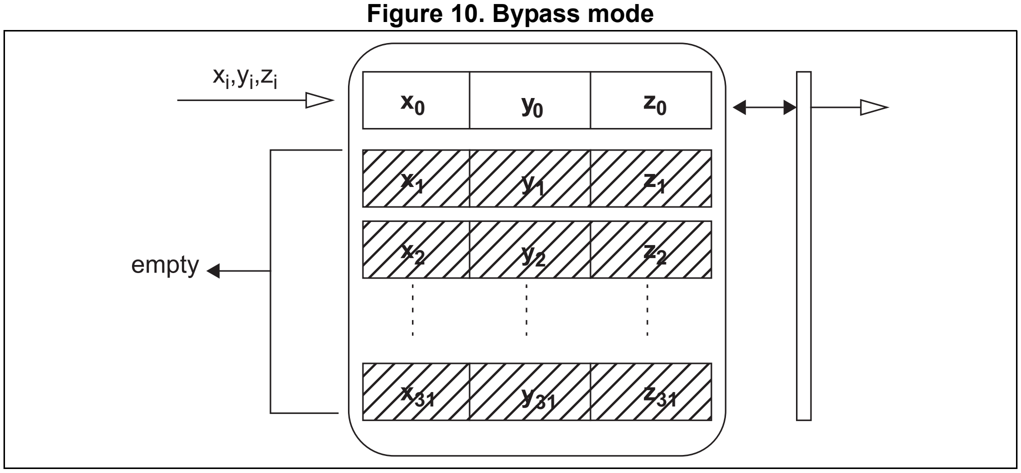
3.5.1 Bypass mode

In Bypass mode (*FIFO_CTRL (2Eh)*(FMODE [2:0]= 000), the FIFO is not operational and it remains empty.

Bypass mode is also used to reset the FIFO when in FIFO mode.

As described in *Figure 10*, for each channel only the first address is used. When new data is available the old data is overwritten.

Figure 10. Bypass mode



3.5.2 FIFO mode

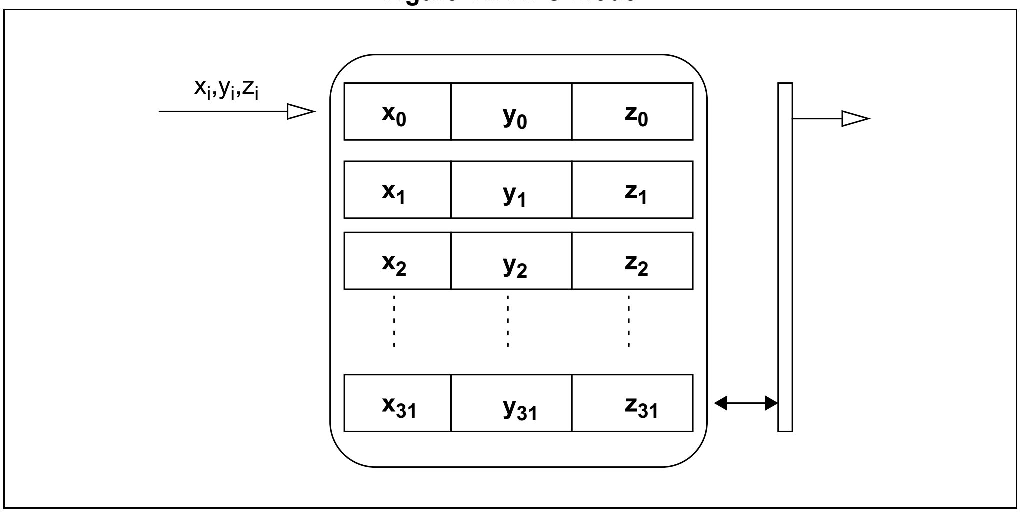
In FIFO mode (*FIFO_CTRL (2Eh)* (FMODE [2:0] = 001) data from the output channels are stored in the FIFO until it is overwritten.

To reset FIFO content, Bypass mode should be selected by writing *FIFO_CTRL (2Eh)* (FMODE [2:0]) to '000'. After this reset command, it is possible to restart FIFO mode by writing *FIFO_CTRL (2Eh)* (FMODE [2:0]) to '001'.

The FIFO buffer memorizes 32 levels of data but the depth of the FIFO can be resized by setting the STOP_ON_FTH bit in *CTRL_REG9 (23h)*. If the STOP_ON_FTH bit is set to '1', FIFO depth is limited to *FIFO_CTRL (2Eh)*(FTH [4:0]) + 1 data.

A FIFO threshold interrupt can be enabled (INT_OVR bit in *INT1_CTRL (0Ch)*) in order to be raised when the FIFO is filled to the level specified by the FTH[4:0] bits of *FIFO_CTRL (2Eh)*. When a FIFO threshold interrupt occurs, the first data has been overwritten and the FIFO stops collecting data from the input channels.

Figure 11. FIFO mode



3.5.3 Continuous mode

Continuous mode (*FIFO_CTRL (2Eh)*(FMODE[2:0] = 110) provides continuous FIFO update: as new data arrives the older is discarded.

A FIFO threshold flag *FIFO_SRC (2Fh)*(FTH) is asserted when the number of unread samples in FIFO is greater than or equal to *FIFO_CTRL (2Eh)*(FTH4:0).

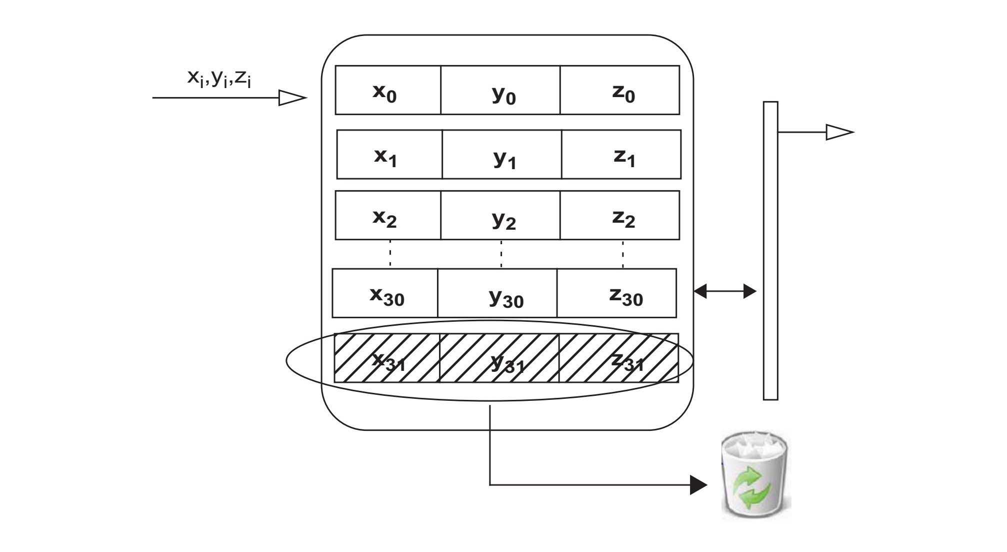
It is possible to route *FIFO_SRC (2Fh)*(FTH) to the INT1_A/G pin by writing in register *INT1_CTRL (0Ch)* (INT1_FTH) = '1', or to the INT2_A/G pin by writing in register *INT2_CTRL (0Dh)* (INT2_FTH) = '1'.

A full-flag interrupt can be enabled, (*INT1_CTRL (0Ch)* (INT_ FSS5)= '1') when the FIFO becomes saturated and in order to read the contents all at once.

If an overrun occurs, the oldest sample in FIFO is overwritten and the OVRN flag in *FIFO_SRC (2Fh)* is asserted.

In order to empty the FIFO before it is full it is also possible to pull from FIFO the number of unread samples available in *FIFO_SRC (2Fh)* (FSS[5:0]).

Figure 12. Continuous mode



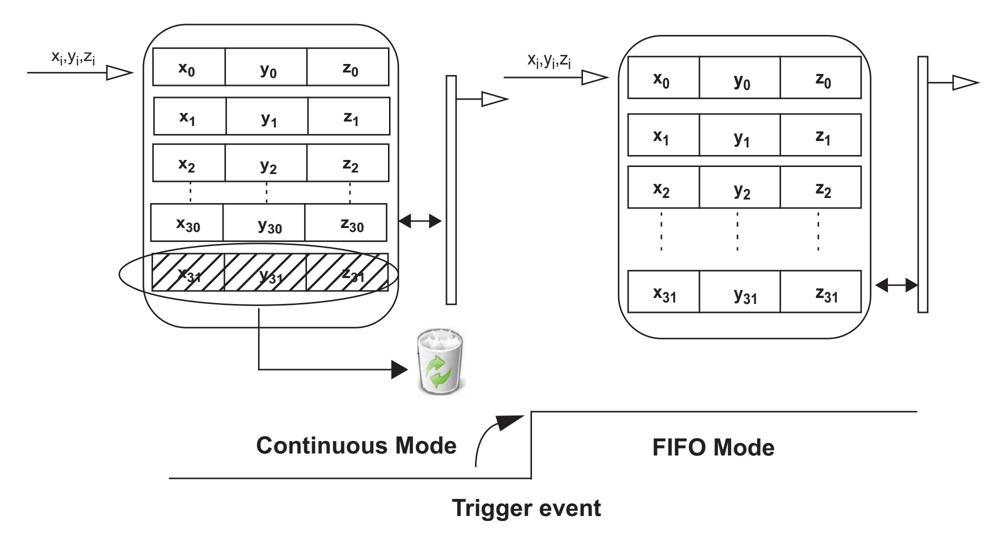
3.5.4 Continuous-to-FIFO mode

In Continuous-to-FIFO mode (*FIFO_CTRL (2Eh)*(FMODE [2:0] = 011), FIFO behavior changes according to the *INT_GEN_SRC_XL (26h)*(IA_XL) bit. When the *INT_GEN_SRC_XL (26h)*(IA_XL) bit is equal to '1', FIFO operates in FIFO-mode, when the *INT_GEN_SRC_XL (26h)*(IA_XL) bit is equal to '0', FIFO operates in Continuous mode.

The interrupt generator should be set to the desired configuration by means of *INT_GEN_CFG_XL (06h)*, *INT_GEN_THS_X_XL (07h)*, *INT_GEN_THS_Y_XL (08h)* and *INT_GEN_THS_Z_XL (09h)*.

The *CTRL_REG4 (1Eh)*(LIR_XL) bit should be set to '1' in order to have latched interrupt.

Figure 13. Continuous-to-FIFO mode



3.5.5 Bypass-to-Continuous mode

In Bypass-to-Continuous mode (*FIFO_CTRL (2Eh)*(FMODE[2:0] = '100'), data measurement storage inside FIFO operates in Continuous mode when *INT_GEN_SRC_XL (26h)*(IA_XL) is equal to '1', otherwise FIFO content is reset (Bypass mode).

The interrupt generator should be set to the desired configuration by means of *INT_GEN_CFG_XL (06h)*, *INT_GEN_THS_X_XL (07h)*, *INT_GEN_THS_Y_XL (08h)* and *INT_GEN_THS_Z_XL (09h)*.

The *CTRL_REG4 (1Eh)*(LIR_XL) bit should be set to '1' in order to have latched interrupt.

Figure 14. Bypass-to-Continuous mode