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System Design for Low Power Applications with Digital MEMS Sensors

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Summary:
System design for low power applications has been significantly simplified by the introduction of new digital MEMS sensors. Engineers can employ several methods at sensor and at system level to optimize power consumption without sacrificing the performance of their applications.

Keywords: low power, MEMS sensor, application, system design, machine learning

Motivation

With continuously increasing number of applications that are utilizing MEMS sensors to measure environmental, motion and other types of data, system engineers need to deal with tradeoffs every day. The applications require more and more features and functionalities, but at the same time they demand to decrease overall system power consumption.

Features of digital MEMS sensors and system level techniques that designers may exploit in order to minimize power consumption are discussed in this paper.

Low Power Sensor

Wide popularity of battery-operated nodes motivated manufactures of MEMS sensors to develop devices with ultra-low current consumption. The newest accelerometers can measure movements while consuming less than one microamp. Even larger improvements have been done in the design of gyroscopes, where we have seen nearly 10times drop in their current consumption just over last couple of years.

Digital MEMS sensors are very flexible in their configuration offering variety of operating modes with associated output resolution and wide range of applicable data rates. Designers can therefore select the most suitable configuration for each application case. Some sensors are even capable to switch their operating mode and data rate autonomously based on an external motion event.

Even though these improvements are of substantial help in low power system design, the newest MEMS sensors bring more features that can help.

Standard Embedded Features

Motion detection features like wake-up (for system activation based on a motion), free fall (detection of device falling on the ground), orientation detection (used daily in our mobile phones), single & double tap (for enhanced user interface) became almost industry standard. More and more common are also features like step counter or pedometer, tilt detection etc.

The above-mentioned features allow the system to offload the microcontroller from continuous acquisition and evaluation of sensor data bringing a substantial decrease in system power consumption. It is simply achieved by the utilization of interrupt signals routed from the sensor to the microcontroller. The microcontroller is not involved in data acquisition, instead it is solely waiting for a signal from the sensor raised just in the moment when there is a new event to be handled by the system.

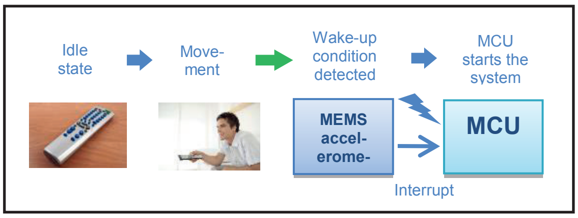

Fig. 1. System wake up utilizing embedded feature and interrupt of MEMS accelerometer.

Advanced Embedded Features

The latest six axis inertial measurement units (IMUs) from STMicroelectronics bring system power reduction to a next level as discussed in [1]. Thanks to Finite State Machine and Machine Learning Core blocks it is possible to move medium complex algorithms from microcontroller inside the sensor itself and consequently reduce not just microcontroller's current consumption and load, but also traffic on communication bus.

Finite State Machine

Finite State Machine (FSM) provides to designer possibility to create his own state program, where in each state two conditions may be evaluated, or a command executed. The conditions can be evaluation of sensor output data with respect to a user-defined threshold or time-related condition based on an internal timer. FSM is well suited for implementation of gesture recognition algorithms.

Machine Learning Core with AI

Machine Learning Core (MLC) is a hardware implementation of decision trees inside IMU sensor. The sensor can run motion classification algorithms by its own and take the advantage of machine learning techniques well known from the field of artificial intelligence.

The utilization of MLC follows common machine learning process. It starts with data collection and labeling followed by identification and extraction of the features that characterize the movements to be recognized. Then any conventional machine learning tool is executed to generate decision tree. Finally, the decision tree is converted into set of values, which shall be loaded into the sensor's configuration registers to run the decision tree algorithm.

The overall system current consumption is dramatically reduced as can be seen from the following example. We took human activity recognition algorithm and compared its implementation as microcontroller library vs. MLC algorithm.

Tab. 1: Current consumption of ST's MEMS sensor when running activity recognition algorithm

Sensor	MCU library implementation	MLC implementation
Core	15 µA	15 µA
MLC	0 µA	4 µA

As shown in Tab 1. in both cases the sensor needs 15 µA to sample data. Running algorithm inside MLC adds just few extra micro amps.

Tab. 2: Current consumption of microcontroller when running activity recognition library

MCU	Wake up rate	Consumption
STM32L476 (Cortex-M4)	63 ms (1/16 Hz)	51 µA

As shown in Tab 2. when the microcontroller is running activity recognition library, it needs to collect sensor data at certain rate (16Hz in this case) and run the classification algorithm.

Tab. 3: Current consumption of microcontroller when running activity recognition algorithm in MLC

MCU	Wake up rate	Consumption
STM32L476 (Cortex-M4)	1 s	2.8 µA
	30 s	0.7 µA
	100 s	0.6 µA

When MLC is running activity recognition, the microcontroller can be left for most of the time in a very low power mode and wakes-up only upon notification from the sensor that a new motion class has been detected, see Tab 3.

From Low Power Sensor to Low Power System

We have seen that sensors offer many options to optimize overall system current consumption. There are several methods how to save current also at the system level as discussed in [2].

The output data shall be read from the sensor using so-called data ready interrupt instead of continuously polling status register to check whether new data has been sampled.

Communication on the serial bus between the sensor and the microcontroller is another contributor to the overall system power consumption. SPI interface is therefore preferred over I^2C. Brand new sensors are equipped with MIPI $I3C^{SM}$ bus that combines benefits of SPI, i.e. speed, and I^2C, i.e. number of wires.

Power supply level shall be as low as possible, because it decreases the current consumed by the sensor. Some applications can benefit from power cycling, mechanism where the sensor is powered only for necessarily short period of time and remains unpowered for the rest. For this purpose, the sensor can be even powered directly from a pin of microcontroller.

Conclusion

Low power system design can benefit from the ultra-low current consumption of modern digital MEMS sensors and utilization of their standard and advanced embedded features like FSM and MLC. By employing optimizations also at the system level, the overall power consumption can be reduced multiple times.

References

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