Next smart sensors generation

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Abstract—Smart sensors are defined by the IEEE 1451 standard as sensors with small memory and standardized physical connection to enable the communication with processor and data network. Beyond this definition, smart sensors are defined as the combination of a sensor with signal conditioning, embedded algorithms and digital interface. They are currently highly adopted in mobile and portable devices like phones and tablets. Such types of sensors respond to the issues of power consumption, data communication and system integration at the sensor level and for predefined use cases. Some limitations of smart sensors are the lack of flexibility, absence of customization, narrow spectrum of applications, and the basic communication protocol. Moreover, there is a growing request of new and broader applications for individual sensors while integrating an increasing number of different types of sensors. Therefore, to overcome these limitations and address the new challenges, the next generation of sensors is proposed: the intelligent sensor platform. It is defined as the combination of sensor and processing with a dedicated architecture to aggregate external sensor data. The main advantages are reviewed and an implementation of an intelligent sensor platform embedding a MEMS accelerometer with a 32-bit microcontroller is described.

Keywords – MEMS, smart sensor, intelligent sensor, sensor network, intelligent motion sensor platform

I. INTRODUCTION

Thanks to the semiconductor technologies and its Moore's law along with the MEMS (Micro-ElectroMechanical Systems) technology, sensors are becoming more cost effective, smaller, less power hungry, with more embedded features. The trend towards pervasive sensors is reflected by the adoption rate of accelerometers in mobile phones - 29% in 2009 and projected to be 34% in 2010 [1]. The earlier adoption of these sensors showed an adoption based on a basic function need – portrait/landscape phone position detection - and an easy implementation of the sensor through a digital interface – I2C – and a small form factor – 3x3 millimeters.

Since 2009, with the launch of products like the MMA8450Q [2], accelerometers became "smarter" by adding embedded algorithms and features, hence, minimizing the data communication flow and the power consumption of the system, while simplifying the development of applications. The sensor not only provides digital data but can also provide the expected information. For instance, functions like portrait/landscape, specific tap and free fall detections can be left to the sensor due to its capability to detect such simple information with values preset by the device manufacturer.

The IEEE 1451.4 standard [3] is defining smart transducers and the MMA8450Q is matching the node class 1 category.

Adding more sensors and different types of sensors to a system is providing a solution with a rich environment and user interaction – from user interface to robots. However, even if smart sensors are matching a lot of existing applications, like mobile phones and sensor networks, they are not responding to the challenges of sensor data aggregation like: more data to be processed in real time, higher ratio of unnecessary collected data and useful data, and lack of data aggregation before processing. Moreover, the power consumption of the system is increasing at the sensor and processing levels. Another challenge and limiting factor of implementing more sensors is the level of complexity to implement more sensors and to design software adapting to each new sensor – like the calibration, specific data management, interface, data sampling rate, and sequence.

Therefore, to provide a solution to these challenges along with higher flexibility while enabling customization and new applications, the concept of the intelligent sensor is described and illustrated with a product: The MMA9550L.

II. ADVANTAGES AND LIMITATIONS OF SMART SENSORS

Smart sensors, including signal conditioning and embedded functions, are more and more adopted by the market - like mobile phones, consumers, and industrial – and gradually replacing the basic sensors. Figure 1 is illustrating the structure of such a smart sensor.

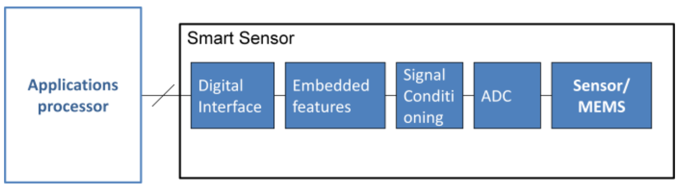

Figure 1: Smart sensor structure

The smart sensor adoption is motivated by the following advantages:

- Reduction of the data communication with the main applications processor for some preset functions with a specific value
- Lower system power consumption since some data is filtered and not all of the processing needs to be done by the main processor

- Easier integration due to standard digital interface and pre-defined functions, avoiding developing all applications from raw data

An example is the portrait-landscape detection with a smart motion sensor which can be achieved through an embedded algorithm – the inverse sine of the acceleration of each axis with registers setting the hysteresis threshold, the de-bounce value, and angle detection [2]. A "non-smart" sensor needs to continuously gather data through the digital interface and a smart sensor, with the portrait-landscape function and an external interrupt feature, is only providing the data when the detection reaches the selected setting. Hence, 10,500 bits/second are necessary in the first case compared to only 41 bits for the smart sensor (annex 1). The difference in data processing is even greater since no processing is necessary in case of the smart sensor, only data fetching.

This substantial savings in data rate and data processing is clearly showing advantages of embedding algorithms at the sensor level. However, smart sensors have some limitations:

- Embedded functions; pre-defined at the design of the smart sensor and with limited register settings
- Customization is not possible; only adjustments of threshold and values through registers
- Application spectrum is narrowed; the type and the number of the embedded functions are limited
- Sensors data aggregation is not addressed
- Sensor calibration needs to be managed by an external processor
- Communication protocol is still basic; relying on standards like I2C and SPI with interrupts

Therefore, to increase and accelerate the adoption of sensors based applications while enabling innovative applications, the sensors need to continue the evolution towards an intelligent sensor: Adding computation capability, memory, and extra interfaces embedded to the sensor.

III. Intelligent Sensor

Overcoming smart sensors limitations and extrapolating the IEEE 1451.4 standard [3] the intelligent sensor is also redefining the software and hardware architecture of applications based on sensors. In fact, intelligent sensors are broadening the scope of applications based on sensors.

A. The concept

The intelligent sensor concept is based on adding the possibility of processing the sensor data, the flexibility to reconfigure embedded functions, and also to aggregate external sensors data. Since it is an evolution of smart sensors, no penalties in term of cost and performance are expected.

Therefore, the outcome is the combination of a sensor, a small microcontroller, the necessary memory – flash, RAM and ROM –, and an optimized architecture for sensor applications. The key constraints are relative to existing sensors:

- Not to exceed the form factor of an existing sensor,
- Minimize the extra cost,
- Equivalent inner power consumption

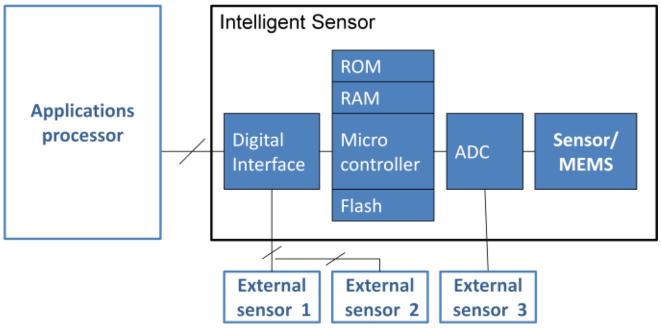

Figure 2: Intelligent sensor structure

The intelligent sensor structure in an application (figure 2) is enabling the customization of the embedded algorithms to specific applications; moreover, the customization can happen on-the-fly by reprogramming the flash.

Since a microcontroller is available, the management and control of external sensors – basic or smart sensors – or external devices – like LEDs - is now possible (figure 2). An optimized architecture with at least two digital interfaces, master and slave and one analog input are necessary to respond to this extra functionality.

The main issue of the intelligent sensor is the software partitioning with the applications processor since this concept is new to most software engineers. Bridging this bottleneck can be done by analyzing the different use cases of the full system.

Even if it is clear that the intelligent sensor main task is to pre-process the sensors data and manage external devices, this can significantly save power consumption and application data processing while providing a faster independent response. Additionally, works on micro-Kalman filters are showing a high scalability in sensor networks [4].

The advantages and implementation of this concept are described in the next section.

IV. Intelligent Motion Sensor

A. Key features of intelligent motion sensors

The industry's first implementation of an intelligent sensor is using a 3-axis motion sensor – dynamically configurable up to 8g - as the embedded sensor since its adoption rate is 34% in mobile phones [1]. Besides acceleration measurement, it can also be utilized for detecting any user or device activity by detecting vibration.

Due to the intelligent sensor constraints in terms of size, the Coldfire® V1 [5] - a compact 32-bit RISC microcontroller – is the embedded MCU (Microcontroller Unit) of choice since it fits very well with low-cost processing data applications.

The architecture based on this Coldfire V1 has been designed to fit sensor applications since it encompasses a multiply-accumulate unit (MAC) for intensive algorithms, a timer and mailbox controller. One SPI and one I2C interface allow a wide spectrum of applications processors and sensor interfacing. Moreover, extra features like a PWM (Pulse Width Modulation) and GPIO are useful to adapt the control of any kinds of sensors and devices. The internal ADC – 14-bit resolution – can be accessible through the GPIOs and the data processed by the MCU. The ROM (Read Only Memory) is housing the boot loader and some basic functions; the flash memory is used by the applications to customize the intelligent sensor.

All of these features are fitting in a 3 x 3 millimeter package, which is the same size of a stand-alone accelerometer. This very small real estate is necessary for mobile and portable devices.

The communication efficiency has been improved by using the internal memory to buffer collected data to be processed or to be provided through the digital interface. Mailboxes and interrupt priorities allow an easy and efficient management of all the different tasks.

The MMA9550L performance is in-line with the key constraints since less than 50µA, at a data sampling rate of 1.6 Hz has been achieved.

Figure 3 shows the MMA9550L with the main blocks in a typical application.

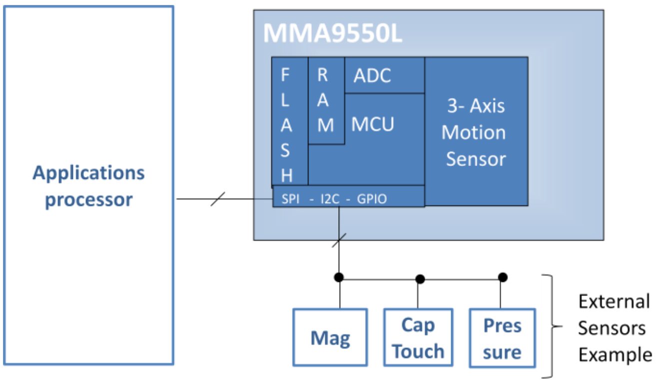

Figure 3: MMA9550L, the intelligent motion sensor platform and an application example

V. ADVANTAGES OF THE INTELLIGENT MOTION SENSOR PLATFORM

Moving parts of the data processing at the motion sensor node level with the possibility to control other external sensors allows to:

- Reduce data communication from the sensor cluster to the main applications processor,
- Aggregate data from different sensors,
- Reduce the power consumption of the overall system,
- Enable customization of each sensor node through software,
- Continuous calibrating and monitoring of the sensors
- Adaptive sampling rate, auto-wakeup and auto-sleep features
- Shorter software development time
- External sensor agnostic

Since the sensor data is processed at the sensor level with the possibility of storing the outcome, the intelligent sensor is only providing to the main application processor the expected data. Moreover, the data from external sensors can be also processed and combined to provide the right information. For instance, in the case of a 3-axis electronic compass, the data of the 3-axis accelerometer and the data of the 3-axis magnetometer have to be sampled and combined for providing the magnetic heading with the tilt compensation. Even if the sampling rate is between 10 Hz to 100 Hz, it is requiring two digital buses, a continuous data flow and the utilization of an applications processor to display the compass. Using the intelligent sensor reduces the number of buses by two and the number of data by six since only the compensated heading is provided. Moreover, no extra processing is needed and the compass application can directly use the data from the sensor.

This data communication reduction and sensor aggregation can be extended to more sensors connected to the intelligent sensor hubs. Another advantage is the possibility to process, aggregate and store the data while the main applications processor is on standby or idle mode. Then the computed information can be transferred in burst mode by interrupting the main processor, thus, saving even greater system power consumption. For instance, typical applications processor like the i.MX51 which consume about 12mA in low-power mode, meaning computing at the minimum clock speed and not displaying any data. In this mode, this processor is gathering data from peripheral devices at low-speed until a user interrupt. By adding the MMA9550L, some of the key external devices, like sensors or touch screen, can be managed and their data processed. Therefore, the management task is consuming less than 100µA instead of 12mA since the applications processor can be set in standby instead of low-power mode. Such saving reflects one of the advantages of the distributed computing.

The advantage of using an accurate motion sensor in this platform is the possibility to use it to detect the device or user activity. Since this sensor is autonomous, it can be the master for the power management of the full system by monitoring the vibration of the device at a low sampling rate. If a movement is detected, then the sampling rate is automatically increased for a more accurate analysis of the motion. Then, if the motion is analyzed as being a real activity, the MMA9550L can wake-up the main applications processor by using one of two interrupt pins. Using the applications processor example, power consumption saving is achieved by cutting the power from normal mode – in the range of 500mA - to low-power or standby mode during user inactivity. The same kind of scenario can be applied for the automatic sleep of the device since the detection of no activity for a defined time will generate the command for the standby.

The flash memory can be easily reprogrammed through the I2C which means that each sensor can be customized to a specific set of applications and devices but it can also be customized at the individual user. This flexibility allows improved and new applications during the life of the device but also the adaptability to add new sensors in a system since it is easier to re-program this simple platform rather than a whole system supporting operating systems.

Such adaptability to new kinds of sensors is not only done at the interface level, but also for the specific calibration and setting necessary for each sensor like a magnetometer for instance.

An application using more than one type of sensor can benefit from this concept since only a high level of programming is needed because the requested sensor data is already processed. The main core of the software can be re-used from one platform to the other since the adaptation is done at the intelligent sensor platform level, which makes systems agnostic to the supplier of external sensors. The outcome is shorter development time and saving in cost for not developing low-level software for data processing.

Therefore, lower communication data, high flexibility, customization and sensor data aggregation and conditioning are some of the advantages of this next generation of smart sensors.

VI. CONCLUSION

This paper is introducing a new concept: The intelligent motion sensing platform. Such a concept is redefining the architecture of sensor and sensor networks [6] by allowing data processing and sensor fusion at the local sensor node level. An implementation combining a MEMS accelerometer, a microcontroller and architecture dedicated to manage external sensors demonstrates some of its advantages. Beyond the savings in cost, power consumption, resources and time-to-market, this concept is allowing new kinds of applications for sensor networks, navigation, home, and industrial uses.

VII. ANNEX 1

The figure 4 is showing the 10,500 bits/second data rate through an I2C interface of a 12-bit 3-axis accelerometer at 100 samples per second.

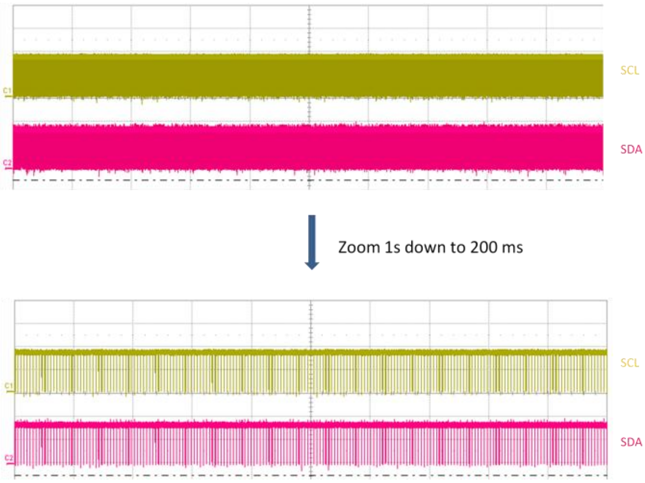

Figure 4: Data rate of a 12-bit 3-axis accelerometer

A smart sensor, which provides the data only when a specific event has been triggered, is using embedded encoded functions and an interrupt to start the communication with the host processor. As shown in figure 5, only 41 data are necessary instead of the continuous flow of 10,500 bits/second.

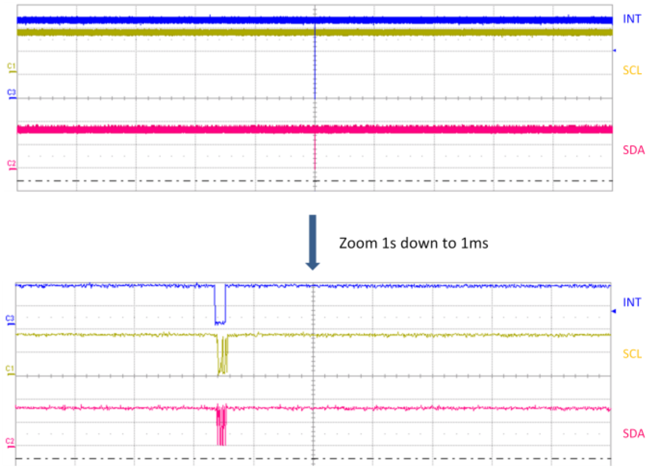

Figure 5: Smart sensor benefit through embedded function and interrupt

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