Smart Tiny Machine Learning Network for Nanomaterial-based Sensors

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1. Introduction

Graphene and other two-dimensional materials, such as carbon nanotubes or nanodiamonds, are often adopted to build innovative microsensors. For example, they can be applied in medicine [1], where nanosensors can detect specific biomolecules, such as proteins or nucleic acids, to diagnose diseases such as cancer or infectious diseases; they can monitor vital signs such as blood glucose concentration or pH. Other application fields are related to pollutant detection, where these microsensors can detect air pollutants, such as nitrogen dioxide or fine particulate matter; water monitoring [2], where they can detect chemicals in the water, such as heavy metals or pesticides and so on. These microsensors often realize wired or wireless sensor networks to cover wider geographical areas to detect more quantities and retrieve measurement information through data fusion techniques [3]. There are three main reasons why these sensors are widely used: a) these materials show great sensitivity to quantities such as temperature, humidity, and chemical substances and, therefore, implement sensors with high sensitivity and good measurement resolutions; b) their input/output characteristics can be modeled as a variation of resistance or impedance, and therefore they can be easily transduced into a voltage with small and cheap circuits; c) they can be deposited or sprayed directly into electrodes or sensing region of microcontrollers. On the other hand, however, their very good sensitivity to different quantities and, in particular, the sensitivity to environmental parameters such as temperature and humidity, the degradation they show over time, especially when operating in critical conditions of use, the very way in which they are deposited or sprayed inside of the microcontrollers make them particularly critical for uses when high accuracy sensing is required and not qualitative measurements or the simple detection of a pollutant. In these cases, by carrying out repeated measurements over time, trends or drifts may appear which are not the result of the variation of the measurand but of the uncontrolled variation of environmental parameters or could be caused by the aging of the sensor or by the modification of electrothermal or physical parameters of the nanomaterial. These trends or drifts could invalidate applications in which long measurement campaigns are required or comparisons between sensors that measure the same quantities but in different places and, therefore, under different environmental conditions.

2. Learning microsensors

To solve this type of problem, new hardware platforms have been created in recent years based on low-cost microcontrollers called tiny machine learning microsensors, which, with the help of advanced measurement information processing techniques and artificial intelligence algorithms on edge, are capable of dynamically compensating for these drift and trend phenomena, allowing the quality of the measurement to be significantly improved. In detail, they have three important features that are very useful in this kind of application: i) the capability to detect drifts or trends unrelated to the measured quantities; ii) the capability to generate firmware to implement suitable measurement routines that update the measurement methods; iii) the Internet of Things. This paper will describe this kind of integrated architecture, which can host the sensors and learn and classify mechanisms ML empowers directly on board. In addition, the paper proposes some examples related to water and pollutant detection with graphene sensors.

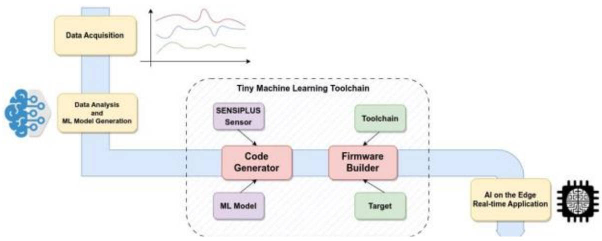

Fig. 1 Possible architecture of a learning microsensor

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4. References

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