Chapter 12

Neural Network Circuits for Embedded Sensors Applications

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ABSTRACT

This chapter presents the suitability, development and implementation of programmable analogue artificial neural networks for sensor conditioning in embedded systems. Comments on the use of analogue instead of digital electronics due to the size and power constraints of these applications are included. Performance of an ad-hoc analogue architecture is evaluated, and its characteristics are analyzed. We will verify its low sensitivity to undesired effects, such as component mismatching, due to the capability of selecting and programming the proper weights for a given task. In addition, a brief discussion is offered on the selection of perturbative algorithms instead of classical error back-propagation techniques for weight tuning. At the end of the chapter, we will show the main characteristics of the proposed arithmetic cells implemented in a low-cost CMOS technology.

INTRODUCTION

Today’s sensor market is advanced towards the so called smart sensors, that is, integrated sensor systems that contain on a single chip the sensing, interfacing, signal processing and intelligence (self-testing, self-identification and self-adaptation) functions (Meijer, 2008). Due to the capability of co-integration of sensors and sensor electronics, research challenges are focused on
Neural Network Circuits for Embedded Sensors Applications

the implementation of low cost high performance CMOS smart sensors. Furthermore, if these smart sensors target the ever-increasing wireless sensor network (WSN) market, low-voltage low-power electronic circuits are required to maximize the lifetime of the battery operated systems.

To standardize the sensor output response, the transfer function from the sensor input to the electrical output should be the same for all sensors of the same type. However, due to process variations, properties vary from device to device and so do transfer characteristics. Therefore, calibration is mandatory to achieve a precise relationship between the electrical output and the physical signal being measured. Accurate sensors are usually more expensive than uncalibrated ones as the calibration process is individually carried out for each device, which pushes up production costs. Alternatively, automation of calibration is possible provided that the smart sensor contains a digitally programmable calibration function. This not only reduces costs and minimizes calibration time at the factory, but also allows the customer to perform recalibration if necessary (van der Horn, 1998).

Several methods are available for calibrating linearity errors in the sensor transfer characteristic, such as piecewise-linear interpolation, look-up table based linearization and electronic implementation of the inverse function of the sensor curve (Subramanian, 2005; Kolle, 2004; Pertijs, 2001). Another option is the use of artificial neural networks (ANNs), which, for linearization purposes, are made up of only a small number of programmable neurons or processing units. As a result, ANNs constitute a flexible solution at a low cost in terms of area, power consumption and computational complexity, thus being a valuable choice for adaptive sensor processing in embedded applications.

Recent technological advances allow a large number of battery-operated, inexpensive wireless networked sensor devices to be embedded in the physical environment. Wireless sensor networks allow for device mobility, fast and easy installation and relocation according to needs. Application fields cover natural habitat monitoring, structure health controlling, environmental pollutant detection, seismic structural damage monitoring, industrial process control and military target tracking, among others (Krishnamachari, 2005). The use of batteries to supply the system permits some of their main features, such as mobility or system ubiquity. In order to achieve long battery life (months or even years), power consumption must be carefully managed (Krishnamachari, 2005; Martinez, 2004).

A sensor unit can comprise smart sensors, with digital output and low power modes, and transducers that provide a raw analogue output. Interfacing between such sensors and the digital part of the system often requires conditioning electronics (Harb, 2004; Chao, 2004). An interface circuit consists of an analogue section to improve the sensor output by extending its linear range and reducing cross-sensitivity to other physical variables, and analogue-digital converters (ADC) to digitize the data to be processed by a microcontroller. Programmability allows a more versatile operation for the interface circuit, which can change its behavior according to the requirements. A classical programmable solution is a polynomial compensation (Khachab, 1991). This solution can be affected by mismatches, leading to reduced performance. Literature today shows more sophisticated solutions, (as in Cavalcanti, 2003), where a programmable analogue circuit is presented to amplify the signal supplied by a sensor, compensating the output offset. In this case, the system merely fits the output signal span to the input range of the ADC available in the microcontroller, but the sensor non-linearities are not corrected. In (Lopez-Martín, 2007), a versatile conditioning circuit for automotive applications is presented. In this case, the system consists of both analogue and digital elements, and power is provided by the car battery, so the adaptation to portable battery operated applications is difficult.