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Smart motion detection sensor based on video processing using self-organizing maps

Francisco Ortega-Zamorano[a,b], Miguel A. Molina-Cabello[a], Ezequiel López-Rubio[a,*], Esteban J. Palomo[a,b]

[a] Department of Computer Languages and Computer Science, University of Málaga, Málaga, Spain
[b] School of Mathematics and Computer Science, University of Yachay Tech, San Miguel de Urcuquí, Ecuador

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ABSTRACT

Most current approaches to computer vision are based on expensive, high performance hardware to meet the heavy computational requirements of the employed algorithms. These system architectures are severely limited in their practical application due to financial and technical limitations. In this work a different strategy is used, namely the development of an inexpensive and easy to deploy computer vision system for motion detection. This is achieved by three means. First of all, an affordable and flexible hardware platform is employed. Secondly, the motion detection algorithm is specifically tailored to involve a very small computational load. Thirdly, a fixed point programming paradigm is followed in implementing the system so as to further reduce the computational requirements. The proposed system is experimentally compared to the standard motion detector for a wide range of benchmark videos. The reported results indicate that our proposal attains substantially better performance, while it remains affordable and easy to install in practice.

1. Introduction

Motion detection is the process of detecting a change in the position of an object relative to its surroundings or a change in the surroundings relative to an object. Motion detection can be achieved by either mechanical or electronic methods, but it is most usually implemented by electronic sensors.

Motion sensors can be passive or active. Passive sensors do not emit any energy to the environment and they are the most common kind of electronic sensors. They are sensitive to a person's skin temperature through emitted blackbody radiation at mid-infrared wavelengths, in contrast to background objects at room temperature. On the other hand, active sensors emit some type of signal like light, microwave or sound into the environment and they detect some change in the behavior of the responses.

Currently new techniques are being introduced in motion detection systems with the proliferation of digital cameras capable of shooting video. Nowadays it is possible to use the output of such a camera to detect motion in its field of view using software. Motion detection is usually carried out by a software-based monitoring algorithm. When the algorithm detects motions it signals the surveillance camera to begin capturing the event. This is also called activity detection. An advanced motion detection surveillance system can analyze the type of motion to see if it warrants an alarm (García, García, Ponz, de la Escalera, & Armingol, 2014; Gómez, García, Martín, de la Escalera, & Armingol, 2015).

The Self-Organizing Map (SOM) is a kind of artificial neural network which is capable of unsupervised learning (Kohonen, 1982). Since its proposal, the SOM has been applied to knowledge discovery, data mining, detection of inherent structures in high-dimensional data and mapping these data into a two-dimensional representation space (Kohonen, 2013; Yin, 2008). This mapping retains the relationships among input data and preserves their topology. Hence this artificial neural network has had a wide range of application fields over the decades (Oja, Kaski, & Kohonen, 2003; Kaski, Kangas, & Kohonen, 1998). In particular, it has been applied to several areas of computer vision, such as color quantization (Dekker, 1994; Palomo & Domínguez, 2014; Papamarkos, 1999; Xiao, Leung, Lam, & Ho, 2012), and image segmentation (Bhandarkar, Koh, & Suk, 1997; Dong & Xie, 2005; Lacerda & Mello, 2013; Maddalena & Petrosino, 2008a). The SOM is based on an incremental (online) learning process, which has better ability to escape from local minima than batch learning (Bermejo & Cabestany, 2002) and consumes less computational time in

* Corresponding author. Fax: +34 952 13 13 97.
E-mail addresses: fortega@lcc.uma.es (F. Ortega-Zamorano), miguelangel@lcc.uma.es (M.A. Molina-Cabello), ezeqlr@lcc.uma.es (E. López-Rubio), ejpalomo@lcc.uma.es (E.J. Palomo).

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color quantization problems (Chang, Pengfei, Xiao, & Srikanthan, 2005). Moreover, it has been employed previously to detect foreground objects in video sequences (López-Rubio, Luque-Baena, & Domínguez, 2011; Maddalena & Petrosino, 2008a). However, these approaches require a SOM for each pixel of the video frame. Consequently a SOM must be trained and queried for each pixel and frame in real time as the video sequence progresses. Therefore they are not suitable for implementation on microcontrollers, which do not have the computational resources to accomplish such a complex task.

All of these schemes require a large amount of computation, which is an important challenge of computer vision systems (Casanova, Franco, Lumini, & Maio, 2013). For this reason it has been necessary the use of PCs to implement these types of learning processes, so that the resultant systems are very expensive and complex to produce on a large scale. In this work we propose changing the strategy to obtain simpler and cheaper motion detectors.

Microcontroller boards are economic, small and flexible hardware devices. They are commonly employed in important technologies such as Embedded systems (Mamdoohi et al., 2012; Marwedel, 2006), Real-time systems (Kopetz, 1997; Wang, Xu, & Gong, 2010) and Wireless sensor networks (Sengupta, Das, Nasir, & Panigrahi, 2013; Yick, Mukherjee, & Ghosal, 2008). They have a reduced amount of hardware resources and limited computing speed, not allowing extensive use of these devices in complex tasks. However, recent advances in the computing power of microcontrollers and a change in their programming paradigm allows the inclusion of learning schemes in the device ("on-chip" learning), adapting their behavior dynamically according to the sensed data (Aleksendrić, Jakovljević, & Irović, 2012; Mahmoud, Lotfi, & Langensiepen, 2013; Ortega-Zamorano, Jerez, Subirats, Molina, & Franco, 2014).

Microcontrollers are frequently employed in motion detection systems due to their low energy consumption and reduced cost. Kinetically challenged people can benefit from microcontroller based input devices specifically designed for them, which measure motion on a plane in real time (Papadimitriou, Dollas, & Sotiropoulos, 2006). A flexible Printed Board Circuit (PCB) prototype which integrates a microcontroller has been proposed to estimate motion and proximity (Dobrzynski, Pericet-Camara, & Floreano, 2012). In this prototype, eight photodiodes are used as light sensors. The efficiency of solar energy plants can be improved by low power systems which estimate cloud motion (Fung, Bosch, Roberts, & Kleissl, 2014). The approximation of the cloud motion vectors is carried out by an embedded microcontroller, so that the arrangement of the solar panels can be optimized for maximum electricity output. Finally, energy-saving street lighting for smart cities can be accomplished by low power motion detection systems equipped with low consumption microcontrollers and wireless communication devices (Adnan, Yussoff, Johar, & Baki, 2015). This way, the street lamps are switched on when people are present in their surroundings.

In the present work, we have fully implemented the SOM in an Arduino DUE board, including the whole learning process to implement the automatic motion detection process for decision-making into the detector in all types of environments, avoiding offline computation and communication to other devices.

The Arduino DUE board was used (Oxer & Blemings, 2009) as it is a popular, economic and efficient open source single-board microcontroller that allows easy project development (Cela et al., 2013; Kornuta, Nipper, & Brandon Dixon, 2012; Lian, Hsiao, & Sung, 2013; Ortega-Zamorano, Jerez, Urda Munoz, Luque-Baena, & Franco, 2015). We also propose a change in the data type representation used in the programming of the Arduino from the floating point representation commonly employed in this type of system to fixed point representation, in order to obtain a faster system with less hardware resources. This enables the utilization of the SOM in this kind of device.

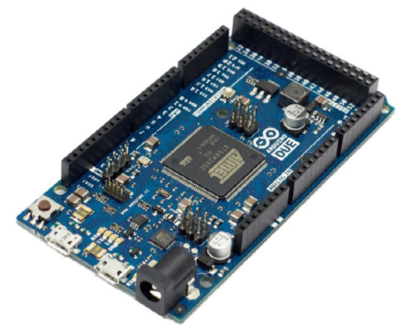

Fig. 1. Picture of an Arduino DUE board used for the implementation of the SOM-based motion detection model.

The paper is structured as follows. In Section 2 the microcontroller system is briefly described, and our fixed point programming approach is outlined. Then we introduce a new motion detection model including the SOM, which is specifically designed to meet the computation capabilities of microcontrollers (Section 3). Section 4 explains the details of the implemented application. The obtained experimental results are reported in Section 5. Finally, conclusions are extracted in Section 6.

2. Microcontroller (μC) system description

We have implemented the SOM-based motion detection model in an Arduino DUE microcontroller. The details of the implemented system are described below, with an emphasis on the comparison between using a fixed point representation or a floating point one. Section 2.1 describes the Arduino hardware, Section 2.2 gives an overall view of the motion detection software, and Section 2.3 discusses the options to implement arithmetic operations.

2.1. The Arduino board

Arduino is a single-board microcontroller designed to make the process of using electronics in multidisciplinary projects more accessible (Oxer & Blemings, 2009). The hardware consists of a simple open source board designed around an 32-bit Atmel ARM core microcontroller, and the software includes a standard programming language compiler that runs in a standard PC and a boot loader for loading the compiled code on the microcontroller. Arduino is a descendant of the open-source *Wiring* platform and is programmed using a Wiring-based language (syntax and libraries), similar to C++ with some slight simplifications and modifications, and a processing-based integrated development environment. Arduino boards can be purchased pre-assembled or do-it-yourself kits, and hardware design information is available. The maximum length and width of the Arduino UNO board are 10.2 and 5.3 cm respectively, with the USB connector and power jack extending beyond the former dimension.

The Arduino DUE is based on the SAM3X8E ARM Cortex-M 3 CPU (Atmel), and it has 54 digital input/output pins (of which 12 can be used as PWM outputs), 12 analog inputs, four UARTs (hardware serial ports), a 84 MHz clock, an USB OTG capable connection, two DAC (digital to analog), and a reset and erase buttons. The SAM3X has 512 KB (two blocks of 256 KB) of flash memory for storing code, it also comes with a preburned bootloader that is stored in a dedicated ROM memory. The available SRAM amounts to 96 KB in two contiguous banks of 64 and 32 KB. A picture of the Arduino DUE board is shown in Fig. 1.

The Arduino Due has a number of facilities for communicating with a computer, another Arduino or other microcontrollers,