ISA Transactions 59 (2015) 434–442

Contents lists available at ScienceDirect

ISA Transactions

journal homepage: www.elsevier.com/locate/isatrans

Colorimetric detection of hazardous gases using a remotely operated capturing and processing system

Roberto Montes-Robles [a], María Esperanza Moragues [a,b], José-Luis Vivancos [a,b], Javier Ibáñez [a], Rubén Fraile [c,*], Ramón Martínez-Máñez [a,b], Eduardo García-Breijo [a]

[a] Centro de Reconocimiento Molecular y Desarrollo Tecnológico (IDM), Unidad Mixta Universidad Politécnica de Valencia – Universidad de Valencia, Camino de Vera s/n, 46022 Valencia, Spain
[b] CIBER de Bioingeniera, Biomateriales y Nanomedicina (CIBER-BBN), Spain
[c] Signal Theory & Communications Department, Escuela Técnica Superior de Ingeniería y Sistemas de Telecomunicación, Universidad Politécnica de Madrid – Campus Sur, Carretera de Valencia km 7, 28031 Madrid, Spain

ARTICLE INFO

Article history:
Received 15 December 2014
Received in revised form
10 September 2015
Accepted 12 September 2015
Available online 3 October 2015
This paper was recommended for publication by Dong Lili

Keywords:
Gas detector
Image colour analysis
Remote sensing

ABSTRACT

This paper presents an electronic system for the automatic detection of hazardous gases. The proposed system implements colorimetric sensing algorithms, thus providing a low-cost solution to the problem of gas sensing. It is remotely operated and it performs the tasks of image capturing and processing, hence obtaining colour measurements in RGB (Red–Green–Blue) space that are subsequently sent to a remote operator via the internet. A prototype of the system has been built to test its performance. Specifically, experiments have been carried out aimed at the detection of CO, CO_2, NO, NO_2, SO_2 and formaldehyde at diverse concentrations by using a chromogenic array composed by 13 active and 2 inert compounds. Statistical analyses of the results reveal a good performance of the electronic system and the feasibility of remote hazardous gas detection using colorimetric sensor arrays.

1. Introduction

The detection of hazardous gases is important for safety reasons in a variety of industrial environments [1], ranging from the aerospace sector [2] to the oil and gas industry [3]. The application of remote gas detection in such environments has benefits related not only with the reduction of risks for human operators, but also with cost savings [4]. The facts that the presence of these gases is dangerous even at low concentrations, and that some of them cannot be perceived by the human smelling system, for instance CO, make their detection an ongoing research issue [5–7]. Several aspects have to be taken into account in the design of remote gas detection systems, including selection of sensing and transmission technologies, choice of system architecture and decision on the degree of automation. In this paper, a system aimed at the remote detection of hazardous gases is described. A prototype of it has been built and results are presented from a laboratory experiment carried out with the purpose of checking the feasibility of its application to the detection of several gases.

Regarding sensing technology, a variety of sensor types have been proposed for gas detection up to now [8], such as electrical/electronic, acoustic, optical spectrographic, and so on. Each type has its own advantages and disadvantages in terms of cost, energy consumption, selectivity, sensitivity, etc. In recent years, colorimetric sensor arrays have been introduced as a new sensing technology for the detection of diverse compounds, both in gas and liquid phases [9,10]. In the case of gases, applications reported in the scientific literature are mainly related to biological processes, such as the food degradation process [11–13] or metabolic diseases [13]. The use of colorimetry for such applications provides solutions at a lower cost when compared to other approaches [10], since colour measurement can be accomplished by means of widely used devices such as flatbed scanners [14] or digital cameras [11], though specifically designed devices have also been proposed [15]. The system presented here has the novelty of extending the range of applications of colorimetric sensors to the case of hazardous gases and it includes a digital camera (a *webcam*) as the image capturing device.

As for transmission technology, design options may be classified into two broad classes: either wireless or wired. System architecture, for its part, will depend on a key decision regarding distance between sensing devices and controllers or actuators. For instance, if sensors are separated from controllers or actuators,

* Corresponding author.
E-mail addresses: romonrob@etsid.upv.es (R. Montes-Robles), mamopon1@upvnet.upv.es (M.E. Moragues), jvivanco@dpi.upv.es (J.-L. Vivancos), jibanyez@eln.upv.es (J. Ibáñez), rfraile@ics.upm.es (R. Fraile), rmaez@qim.upv.es (R. Martínez-Máñez), egarciab@eln.upv.es (E. García-Breijo).

http://dx.doi.org/10.1016/j.isatra.2015.09.010
0019-0578/

wireless connections are a cost-effective solution [16]. But low energy consumption will be a strict requisite for sensors [8] in that case. If sensors and controllers or actuators are not separated, connections may be wired or even sensors be integrated with controllers or actuators [3]. In this case, a communication system that allows remote operation of such controllers or actuators should be designed. With respect to other systems, the one described here has the singularity of the sensing device being independent from the data capturing device. Since the sensing device consists in an array of materials whose colour changes in the presence of gases, and the device that captures such changes is a camera, there is no need for electronic communications between sensors and capturing device. Only line of sight between them is required. The capturing device is connected to the controller by wire and remote operation of the controller is achieved via open standards.

Last, as far as automation is concerned, the design of image capturing and processing systems for colorimetric sensing has to face several issues. One of such issues is the need for constancy of illumination. Some solutions based on the use of computer screens as controllable lighting devices have been proposed to solve this problem [17,18]. Another challenging issue is the identification of sensors' positions within the captured image and the evaluation of their colours, given that sensor surfaces may not be completely flat and that the interaction between sensing material and surrounding gas may not be uniform across the whole surface. This has been solved by some researchers through manual selection of an area within the image from which a colour measurement is obtained [19]. Both issues are solved in the herein presented system by allowing the controller to manage illumination and to automatically process captured images.

Specifically, the proposed system implements colorimetric sensing algorithms on a general-purpose minicomputer [20], thus providing a low-cost solution to the problem of gas sensing. Additionally, the use of a general-purpose minicomputer makes it possible for the same system to automatically perform the functions of lighting control, image capturing, image processing and result reporting. Furthermore, the minicomputer is equipped with a network card that connects it to the internet. This allows it to be remotely operated, therefore avoiding the need for a human operator to be present in the area where gases are to be detected. A detailed description of the proposed system is included in Section 2 (subsection 2.1). A laboratory experiment was carried out in order to provide a proof of concept for the system. The colorimetric sensing array used in this paper is similar to the one described in [11,12]. Further details on the array and the experiments are provided in Sections 2.2 and 2.3. Detection results are presented in Section 3.

2. Materials and methods

2.1. Image capturing and processing system

2.1.1. Hardware

The electronic system in charge of capturing images of the chromogenic array and processing them so as to detect colour changes in the sensing materials is basically composed by a low-cost minicomputer (*Raspberry Pi* [20]), equipped with a webcam (*RaspiCam* [20]) and connected to the internet. The overall system architecture is depicted in Fig. 1 and pictures of the equipment are shown in Fig. 2. Table 1 includes additional technical details of the minicomputer and the camera, while the specific architecture of the lighting system is illustrated by the block diagram in Fig. 3.

The minicomputer controls, via the GPIO (General Purpose Input/Output) port, a LED (Light-Emitting Diode) lighting system. The purpose of the lighting system is to illuminate the scene at the

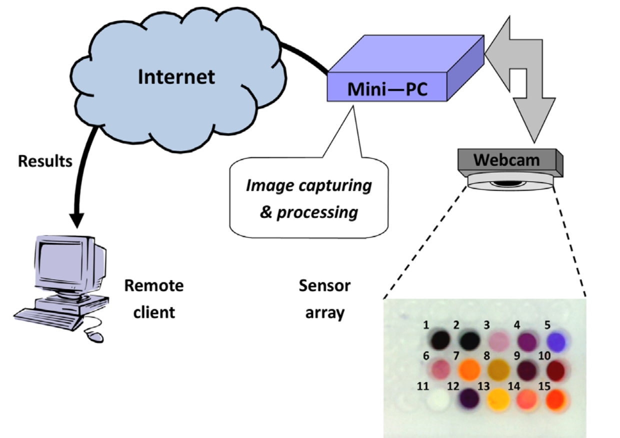

Fig. 1. Overall architecture of the electronic image capturing and processing system.

time of image capturing. The lighting system requires a 24 V voltage source and a current with intensity approximately equal to 1.5 A. However, the output port of the Raspberry Pi(center-left block in Fig. 3) only provides 3.3 V and 20 mA. Thus, a power stage had to be designed to serve as interface between the minicomputer and the LED lighting system. The power stage includes an amplifier based on the IRF640 transistor that is capable of controlling currents up to 18 A (center-right block in Fig. 3). For the amplifier to work properly, a gate-source voltage level of at least 5 V is needed. Such voltage is provided by a logic level converter (3.3–5 V) incorporated to the system (center block in Fig. 3).

2.1.2. Image processing

The image capturing and processing software was developed in Python 2.7 [21] and it makes use of the Open CV library [22]. Both capturing and processing routines are run on the mini-PC and results are subsequently sent via e-mail (Simple Mail Transfer Protocol [23]) to a remote server. The system can be remotely operated by making use of the standard XDMCP (X Display Manager Control Protocol) [24] and SSH (Secure SHell) [25] protocols. Yet, the joint use of a general-purpose computer and high-level programming languages makes it feasible to adapt the system to any other standard communications protocol.

A detailed description of the image processing algorithms is beyond the scope of this paper. Yet, a brief outline of the procedure for locating the probes on the captured image is provided next:

(i) The colour image is first converted to a luminance matrix (see [26] for further reference on colour models and conversions).
(ii) A thresholding operation is performed to yield a binary image.
(iii) After thresholding, noise reduction is achieved by a dilation operation [26].
(iv) Image objects are detected by carrying out a contour detection operation on the binary image, using the algorithm implemented in Open CV.
(v) For the region limited by each contour, its area and centroid coordinates are calculated.
(vi) Based on the area calculations, too large and too small regions are discarded.
(vii) The darkest remaining region (carbon powder, as mentioned below) is then located. This, together with the centroid positions, allows for the estimation of the rotation angle of the probe matrix.
(viii) Information on the rotation angle is further used in conjunction with centroid positions to locate the centre of all the probes.