

VIDEO ANALYSIS OF EVENTS WITHIN CHEMICAL SENSOR NETWORKS

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ABSTRACT

This paper describes how we deploy video surveillance techniques to monitor the activities within a sensor network in order to detect environmental events. This approach combines video and sensor networks in a completely different way to what would be considered the norm. Sensor networks consist of a collection of autonomous, self-powered nodes which sample their environment to detect anything from chemical pollutants to atypical sound patterns which they report through an ad hoc network. In order to reduce power consumption nodes have the capacity to communicate with neighbouring nodes only. Typically these communications are via radio waves but in this paper the sensor nodes communicate to a base station through patterns emitted by LEDs and captured by a video camera. The LEDs are chemically coated to react to their environment and on doing so emit light which is then picked up by video analysis. There are several advantages to this approach and to demonstrate we have constructed a controlled test environment. In this paper we introduce and briefly describe this environment and the sensor nodes but focus mainly on the video capture, image processing and data visualisation techniques used to indicate these events to a user monitoring the network.

1. INTRODUCTION

Sensor networks represent the development of communities of small, autonomous, self-powered sensor devices which have limited communications capability using wireless networks but which can be deployed as collaborating communities of nodes for low-bandwidth monitoring and alert detection [12]. The current dominant approach to developing sensor networks is to configure groups of nodes, such as Berkeley motes [1]. Within such a network, along with the wireless messaging, each node has to be capable of dealing with security issues and the networking protocols to be supported [11], as well as the actual sensing technology to be

embedded within the device, i.e. chemical sensing [5], audio sensing etc. This requires that each node has the computing power to assemble the communications infrastructure and, more importantly, the battery power to consistently and reliably sustain such a network.

In a conventional mote-based sensor node one of the biggest users of power is the energy for communications. In this paper we present a network where communication is based on light signals emitted by LEDs. The LEDs themselves are chemically coated with sensing chemicals which react by changing colour on detection of whatever it is they are monitoring. Such LED signals may be picked up by an existing network of CCTV cameras where coverage of the environment to be monitored is already in place and where the capacity to detect “events” can be based on a combination of LED signals from nodes and video processing of the outputs of the CCTV network. Such coverage of the environment is certainly in place within the built environment such as within city centres, towns, homes, strategic buildings where people will congregate including subways, train stations, airports, etc. This approach has the advantage of reducing the cost of deployment since individual nodes will not be required to create and maintain their own communications infrastructure and so they can be built as simpler, cheaper, and less power consuming devices. We have built a laboratory-based simulation environment where we can locate LED-based sensor network nodes and introduce gas plumes in a controlled manner in order to test the detection and communication between nodes and the monitoring station.

The rest of this paper is organised as follows; in Section 2 we give an outline of the sensor nodes we are using and the environmental monitoring chamber we have built for testing. Section 3 gives the details of the video processing we perform in order to detect signals from the individual nodes and covers the video capture, video processing and output display we have constructed. In Section 4 we present experimental results. While Section 5 outlines our conclusions and future work.

2. SYSTEM SET-UP

2.1. Sensor Nodes

The nodes we have developed are constrained by: processing power, amount of storage space, and the amount of power they can consume. These nodes use Mica2Dot MPR500CA mote devices [1] whose processors run at 4MHz. The sensors are powered using CR2354 3V Li coin cell batteries with a capacity of around 560mA-hr and have a lifetime we estimate as follows. If we assume the duty cycle of a mote is that it is sleeping for 99% of the time and using about 17uA/1% when it is active and using 22-25mA for the main processor, radio and sensor. Then the mote and all extras consumes about 0.237mA-hr and on this basis a 250mA-hr battery will have about 1.45 months of life, while the coin cells we use extend this to about 3 months.

The sensor comprises of 2×1206 surface mount LEDs, both coated with a PVC polymer film containing a pH indicator dye, and use at most 5mA. The basic concept behind the sensing is that this PVC compound will sense some change in the environment. For our environmental monitoring chamber the *event* we detect is a change in pH which we achieve by introducing acetic acid into the chamber. A pH indicator in the PVC coating, coated directly onto the lens of the LEDs, changes colour when acetic acid is introduced, and this change affects the filtering of emitted light from the LED. The way in which the chemical sensing uses the pair of LEDs on each node is that the circuitry in the node enables the LEDs to be switched between *detect* (reverse bias) or *emit* (forward bias) modes [7]. One LED is coated with a chemo-sensitive polymer coating incorporating a pH sensitive dye such as bromocresol green. This LED is operated in detect mode to sense the status of the colour film and is initially blue. A change in the external environment due to the diffusion of a chemical plume generates a colour change in the chemo-sensitive film on the detector LED. This is detected by the circuit which turns on the other, emitter LED. Simple low-cost, low power platforms like this can be used to detect a broad variety of chemical and biological species using colorimetric approaches that are already well known [2, 8].

2.2. Environmental Monitoring Chamber

There are two objectives behind the development of an environmental monitoring chamber. The first, and more ambitious, is the development of a controlled environment that can be used as a test rig to map and model fluid dynamics using a sensor network. Sensors are dispersed within the chamber and their detection of the spread of chemical events can be observed and analysed. The second objective behind developing the chamber is to use it as a testbed for the development of sensor nodes, in particular using the

combined LED sensing and communications approach. The chamber is constructed from bonded 10mm thick clear Perspex sheets and has a dimension of $2m \times 1m \times 1m$. Transparency of the chamber walls facilitates the use of camera equipment to capture the sensor LEDs' responses. A rendered representation of the designed test chamber is shown in Fig 1(a).

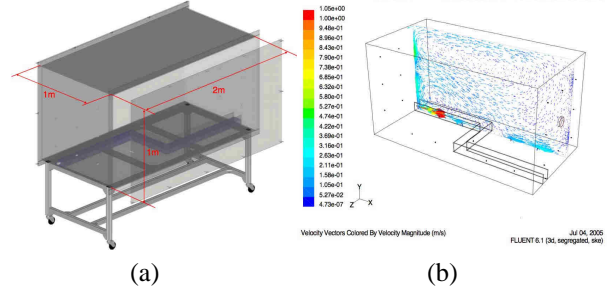


Fig. 1. (a) Schematic of the Environmental Monitoring Chamber. (b) Vector plot of the velocity dispersion of a plume introduced into the chamber.

One important line of research which we are using the chamber for, is to study the dispersion and spread of gas plumes and our current test data have shown that it is possible to activate the sensor devices by passing an acetic acid based plume over them. This indicates that it will be possible to use the sensors to map and predict plume development. A predicted vector plot example of the disbursement of a plume is shown in Fig 1(b) and by placement of sensors at strategic points we would expect to confirm the disbursement by actual readings at such points.

3. VIDEO MONITORING OF A SENSOR NETWORK

It is worth noting that detecting plumes of acetic acid in a perspex chamber is far removed from monitoring and detecting real environmental events in the field. However, whilst our monitoring approach does not necessarily scale to all unconstrained real-world situations, technological advances and declining costs in capture technology, as well as heightened security concerns have led to a rapid diffusion of CCTV surveillance in recent times [9]. Within Europe, circa 30% of publicly accessible space, e.g. shops, banks, restaurants etc., contain some form of video surveillance [10]. Such camera networks could conceivably be used in the future for the kind of data harvesting proposed here. In this section, we describe our capture system, how image processing techniques can be used to identify sensor activity, and the client-server architecture of the system developed to facilitate low-cost low-bandwidth dissemination of the sensed data back to stake holders.

3.1. Video Processing

The goal of video processing in monitoring the chamber is to identify when an LED is triggered to an on/off state. In order to capture video we use a low-end VGA 640×480 resolution CCD camera, which is typical of most CCTV surveillance set-ups. The camera used is equipped with a 6mm lens and a polarized filter in order to reduce visual noise due to lighting reflections from the chamber's transparent and reflective walls.

In general, CCD cameras images are represented within the RGB colour space. In an image pixel values represent a point in this three dimensional RGB space and therefore the difference between two colours can be determined as a distance within this space. The problem with RGB is that these distance measures are very different to the perception of the human eye and are susceptible to noise in the image. Hence, colours which are close together for the human visual system aren't necessarily close in RGB space and vice versus. For this reason the first step we perform is to convert the image to the CIELAB perceptually uniform colour space. This space is optimised according to the perception of the human eye. This transformation involves converting RGB to XYZ, the tristimulus values of CIE, using Eq (1). Then these values are transformed into CIELAB using Eq (2), where X_0, Y_0 and Z_0 are the illumination tristimulus values, further details about this conversion can be found in [4].

$$\begin{aligned} X &= 0.4303R + 0.3416G + 0.1784B \\ Y &= 0.2219R + 0.7068G + 0.0713B \\ Z &= 0.0202R + 0.1296G + 0.9393B \end{aligned} \quad (1)$$

$$\begin{aligned} L^* &= 116f\left(\frac{Y}{Y_0}\right) - 16 \\ a^* &= 500 \left[f\left(\frac{X}{X_0}\right) - f\left(\frac{Y}{Y_0}\right) \right] \\ b^* &= 200 \left[f\left(\frac{Y}{Y_0}\right) - f\left(\frac{Z}{Z_0}\right) \right] \end{aligned} \quad (2)$$

where

$$\begin{aligned} f(q) &= \sqrt[3]{q} & q > 0.008856 \\ f(q) &= 7.787q + \frac{16}{116} & q \leq 0.008856 \end{aligned}$$

The next step is to define a model within this space for the colours of the LEDs we wish to identify. In order to increase the flexibility of the filter we provide an initialisation/training phase whereby valid filter colours within the image can be defined by a superuser in order to build the required filter. After the filter is defined all pixels in subsequently captured frames can be classified on the basis of the LED model.

The colour filter allows us to extract an area of interest (AOI), representing the coloured LED, from the background. In the initialisation phase, the colour intensity of LEDs in the on/off states is measured and a mean value computed. We then generate a histogram of the intensity

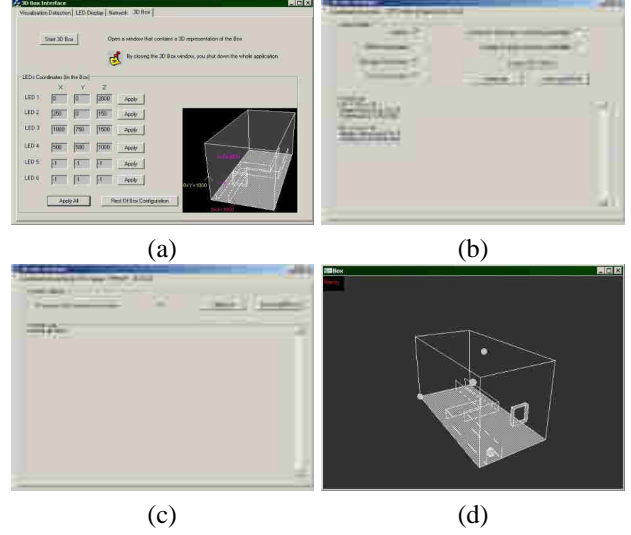


Fig. 2. (a) Manual refinement of automatically detect LED locations. (b) Set-up of information to be sent to client. (c) Client status. (d) 3D view as seen on client side.

values over time within the various AOI. Analysis of local minimums and maximums within this histogram allows us to determine the LEDs current state, i.e. on or off, indicating the triggering of specific events in the monitored environment.

3.2. Capture Control System and Data Visualisation

The design of the interface to control the video capture system and display sensed data follows a client-server architecture. This facilitates full system control at the server whilst supporting multiple remote clients for viewing the output of the video capture system. At the server side, full control is provided over the initialisation phase that is run once prior to any experimentation. This allows setting of various detection thresholds (as outlined above) and visualisation and manual adjustment of automatically detected sensor locations within the chamber. This is shown in Fig 2(a). The interface also provides statistics on the data and this can be logged during an experiment (e.g. colour, 2D/3D coordinates, etc) – see Fig 2(b). Finally, information on client data viewers connected to the system is also provided – Fig 2(c).

The output of video processing, i.e. the location and status of LEDs, is visualised via a 3D wireframe virtual model of the chamber. This allows user navigation in three dimensions around the chamber, allowing free view point inspection of the status of the sensors. This approach to visualisation provides the user with more flexibility whilst requiring a much lower bandwidth transmission link than the original images. The interface, with multiple LEDs detected, is illustrated in Fig 2(d).

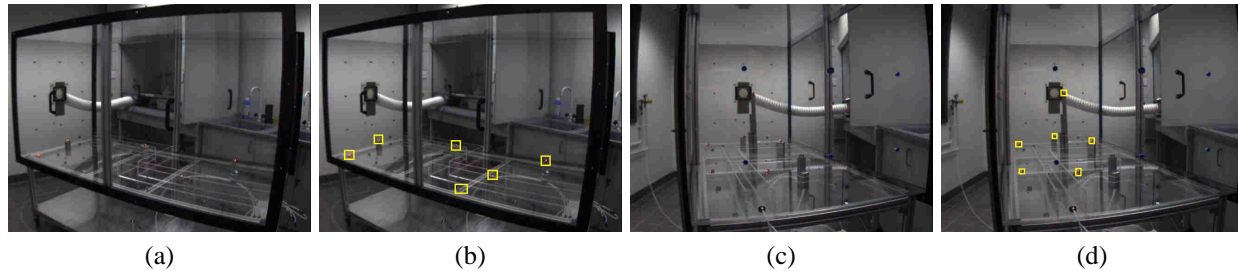


Fig. 3. (a) Image of environmental chamber with 6 LEDs. (b) Yellow boxes indicate identified LEDs. (c) Environmental chamber taken from a different viewpoint. (d) Correctly identified LEDs are indicated by yellow boxes.

4. EXPERIMENTAL RESULTS

In Fig 3(a) we present an example of the scenario where 6 LEDs are in the on state. Fig 3(b) illustrates the identified LEDs by placing yellow boxes around them. Fig 3(c) presents the environmental chamber from another viewpoint and correctly detects a different LED arrangement as indicated by the yellow boxes in Fig 3(d).

5. CONCLUSIONS

In this paper we have introduced the idea of a sensor network for environmental monitoring that communicates back to a base station via video monitoring of LED signals emitted by the sensor nodes. We have demonstrated this working in a chemical chamber which is now operational with a dozen sensors in 3D space. The sensors have a chemically-coated LED for detection and messaging. Identification of the LEDs is done based on colour and analysis of intensity histograms within identified AOI. We have also presented a capture and control system which provides information on various sensor parameters as well as 3D data visualisation for remote monitoring. The advantages of this system are that our nodes require much less power than radio-based solutions, a large number of CCTV networks already exist in built-up areas, and the costs of CCTV installation and monitoring are comparatively cheap.

Our future work is in two directions: to deploy our sensors for actual environmental monitoring in operational situations such as landfill sites, and to investigate using a thermal infra-red camera for video monitoring of the sensor nodes. We will also continue to research technology for use in the chemical sensing which can be used to coat the LEDs and investigate security aspects as well. [§]

6. REFERENCES

- [1] G. Anastasi, A. Falchi, A. Passarella, M. Conti, and E. Gregori. Performance measurements of motes sensor networks.

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- In *MSWiM '04: Proceedings of the 7th ACM international symposium on Modeling, analysis and simulation of wireless and mobile systems*, pages 174–181, New York, NY, USA, 2004. ACM Press.
- [2] S. Baldwin, K. T. Lau, W. Yeraunus, R. Shepherd, and D. Diamond. Colorimetric detection of iron (II) using novel paired emitter detector diode (PEDD) based optical system. *IEICE Trans. Electron.*, E87-C(12):2099–2102, 2004.
- [3] S. Brady, D. Diamond, and K.-T. Lau. Inherently conducting polymer modified polyurethane smart foam for pressure sensing. *Sensors and Actuators A : Physical*, 119(2):398–404, April 2005.
- [4] C. Connolly and T. Fleiss. A study of efficiency and accuracy in the transformation from rgb to cielab color space. *IEEE Transactions on Image Processing*, 6(7):1046–1048, 1997.
- [5] D. Diamond. Internet scale sensing. *Analytical Chemistry*, 76:278A–286A, 2004.
- [6] L. E. Dunne, S. Brady, B. Smyth, and D. Diamond. Initial development and testing of a novel foam-based pressure sensor for wearable sensing. *J. Neuroengineering Rehabil.*, 2(1), 2005.
- [7] K. T. Lau, S. Baldwin, R. L. Shepherd, P. H. Dietz, W. S. Yeraunus, and D. Diamond. Novel fused-LED devices as optical sensors for colorimetric analysis. *Talanta*, 63:167–173, 2004.
- [8] K.-T. Lau, E. McHugh, S. Baldwin, and D. Diamond. Paired emitter-detector LEDs for the measurement of Lead II and Cadmium II. *Sens. Actuator B*, in press, 2005.
- [9] M. Nieto, K. Johnston-Dodds, and C. Simmons. *Public and Private Applications of Video Surveillance and Biometric Technologies*. Californian Research Bureau, March 2002.
- [10] C. Norris, M. McCahill, and D. Wood. The growth of cctv: a global perspective on the international diffusion of video surveillance in publicly accessible space. *The Journal of Surveillance and Society*, 2 Summer:110–135, 2004.
- [11] A. Perrig, J. Stankovic, and D. Wagner. Security in wireless sensor networks. *Commun. ACM*, 47(6):53–57, 2004.
- [12] R. Szewczyk, E. Osterweil, J. Polastre, M. Hamilton, A. Mainwaring, and D. Estrin. Habitat monitoring with sensor networks. *Commun. ACM*, 47(6):34–40, 2004.