Flexible Polymer Film Based Sensor Networks for Invasive and Non-Invasive Medical Monitoring

Martin DUDZIAK, PhD[1]
TETRAD Technologies Group, Inc., USA

Abstract. An instrumentation system based upon laminate polymer film composition with embedded ultra-flat imaging sensors has been designed for application to both external and internal monitoring during medical procedures or post-operative care. This technology is based upon a common architecture employing PET (polyethelene terephthalate) film substrates laminated with conductive printed circuit logic and the inclusion of discrete ultra-flat imaging sensors which are based upon the principle of compound eye vision. The system enables the construction of variable-size, variable-geometry sheets that can be applied physically to different locations including objects in an environment that requires frequent monitoring, with imaging capabilities of each sensor sheet ranging from simple motion detection to richer feature detection that can be processed by human or autonomous software agent observers.

Keywords. Conductive polymer, compound eye, artificial vision, polymer film, sensor fusion, situation awareness, patient safety, history tracking, critical care

Introduction

Within critical-care, emergency and crisis environment situations, particularly outside the confines of the established hospital environment (e.g., in civilian disaster settings or combat locations) medical procedures of diverse type may be performed under drastically adverse resource, lighting, staffing and attention levels. Patient safety and survival as well as the ability to record and review procedures ranging from drug administration to surgical procedures and post-operative monitoring are problem issues in such settings. The experiences of medical personnel in two well-known settings – the Iraq warfront and the post-Katrina flooding and destruction in New Orleans – exemplify the physical and operational context for which new forms of assistance in visual and other means of real-time situation awareness are needed.

Shortage of staff, requirements for sharing critical care equipment, power outages, leaks in hoses, shifting of patients and equipment or furnishings, absence of adequate lighting, power or water - these are among the factors that lead to a spectrum of problems ranging from avoidable patient death or extenuated injury to inability or delay in treating more patients within a limited amount of time, breaks in weather, or

[1] Corresponding author: TETRAD Technologies Group, Inc., 28 Chase Gayton Circle, Suite 736, Richmond VA 23238 USA
Email: martin@forteplan.com

cessation of combat hostilities. We set out to design a multi-purpose solution providing situation awareness when there are not enough human or automated resources to cover normal needs. Our motivation was to extend visual sensing (and potentially other forms such as chemical sensing) to assist those working in critical procedures when breakdowns of normal processes have occurred or are expected.

There are applications and needs as well inside the normal ER, OR, ICU and general clinical operating environment for which the aforementioned problems do occur and for which our proposed solution can work. However, our principal focus has been upon the exacerbated and disadvantaged operational environment, the cases where organizational and supervisory infrastructure also may have collapsed or been stretched to the limits of effective attention and awareness by responders and providers. Particularly we have been motivated by cases, demonstrated in many military actions and civilian disasters, where there is no reliable information flow for tracking procedures and events such as the sequence and dosage of drug administration to patients being treated in a "field setting" and later transported to distant hospitals that are unable to communicate readily with the actual field responders and attendants.

The concept of compound eyes is not new to artificial vision systems [1] and has been principally studied with a view toward engineering visual sensors that can replicate the functions and behaviors of an insect eye for obstacle avoidance or navigation [2]. Our approach has been to take the general model of the compound eye, as well as some specific sensing technology that has been developed following that model for providing vision capabilities in extremely flat and small electro-optics, and to experiment with ways in which this technology can be adapted to high-stress, high-noise, low-resource operational environments and in particularly to situations where it cannot be predicted in advance of need where all the visual sensors should be placed and how they should communicate with one another. Paramount in our architectural design work has been the need to develop solutions that can be used in a diversity of physical locations, power constraints, and interfaces but to also provide a means for adding future capabilities beyond the visual optical spectrum and to achieve all this in an engineering design that will be economical for wide use, even to be discardable in cases where re-use would be impractical due to sterilization requirements that might not be achievable with the type of electronics and materials.

1. System Architecture

The architecture, referred to as the SenseNet, is based upon four components: (1) individual sensor elements (currently considering only visual sensors, described in Section 2) that are embedded (one or more) in Patches, wireless-accessible flexible units. Each Patch consists of a laminate polymer construction involving (2) industry-standard PET (polyethelene terephthalate) film as the primary substrate bonded to a standard neoprene or PVC base layer for additional strength and (3) a OLED (organic light-emitting diode) multilayer with specific HIL (hole injection layer) technology [3] that is laminated to the PET, plus (4) industry-standard wireless communication electronics drawn from conventional 802.11 wireless internet products. SenseNet components are illustrated in Figure 1 and Figure 2 below.

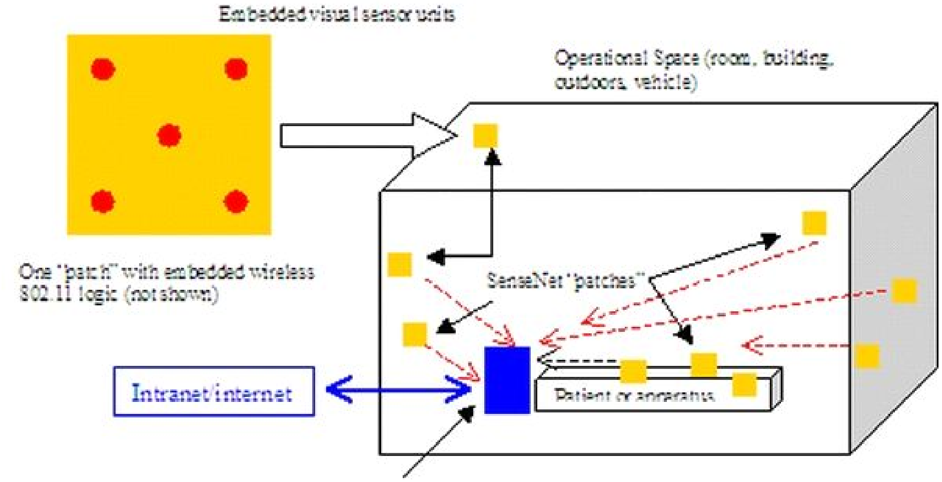

Figure 1 – SenseNet Configuration Schematic

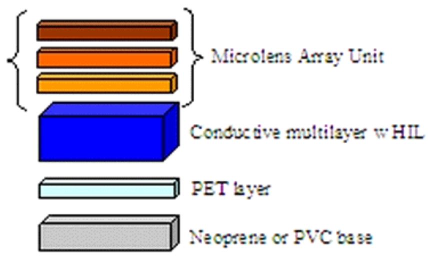

Figure 2 – SenseNet Layering Schematic

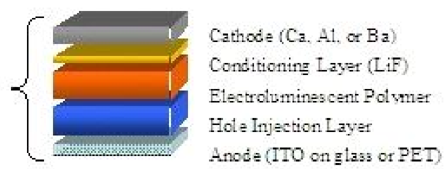

Figure 3 – Conductive Multilayer (shown as OLED) [3]

SenseNet Patch units are each linked to a standard 802.11 access point and thereby into the local intranet or internet that has been established for the operational space. Data communications from Patches are input to a server which in turn maps the image data (or in the case of non-visual sensor data in the form of text) directly into a resident archiving database and a dynamic web management application for interactive display via standard browsers on PC, PDA or other internet accessible devices. In this manner, SenseNet data is real-time provided to the following communities of users:

- Individuals working in the actual operating space
- Observers working remotely or requiring real-time knowledge of the status (visual or otherwise) or of various conditions in the operating space (patient medical observables, status of equipment under visual observation, status of physical lines, cables, tubing, or structures, and historical recording of events such as administration of drugs, movement of patient(s) or equipment, surgical procedure sequences, and anything else that is deemed worthy of monitoring and put under observation by physical placement and adjustment of a SenseNet patch)
- Post-facto viewers and reviewers who have need for a transcript of events that have occurred, such as in the case of caregivers for a patient who has been moved from the battlefront to a base hospital or from a disaster zone to another regional center, or a medical review board investigating a procedural history.

From the standpoint of system integration we have developed software that is designed as an intelligent agent-enabled content management system [4] using C++, Java and PHP-based components, treating the data as a stream of information handled in a conventional extract-transfer-load (ETL) scenario that is common in the management of very large databases and data warehouses. Agents in the ETL pipeline react to both direct demands and inferred associations and pattern recognition events and thereby route sensor (image) data to particular defined dynamic web pages or through notifications sent as email or SMS packets to pre-identified individuals. Thus a wide and extensible variety of people connected with the procedures at hand can be notified real-time of events and relationships (detected patterns) that merit attention and/or intervention. Within the limits of the present paper it is not possible to describe further the content management or fault-tolerance logic used for communications processing.

2. Visual Sensor Units

The visual units are critical to the utility of the SenseNet. We have selected for our study and experimentation the two different methods, one an artificial apposition eye and the other a cluster eye design, developed by Duparre et al [5,6,7]. The designs derive from insect eyes and the Gabor-Superlens. The apposition eye unit has been tested experimentally and returns images that are of high quality at 17cm with a horizontal FOV of 63° achievable for a system employing a 2mm thin imaging system with 21x3 channels, 70° x10° field of view and 4.5mm x 0.5mm image size. This is a promising start for the type of applications discussed in Section 1.

References

[1] Hoshino, K., Mura, F., Morii, H., Suematsu, K. and Shimoyama, I., A Small-Sized Panoramic Scanning Compound Eye Inspired by the Fly's Eye, *1998 IEEE Int'l Conference on Robotics and Automation*, IEEE Press (1998)

[2] *Conference on Neurotechnology for Biomimetic Robots*, Northeastern University, May 14-16, 2000, http://www.neurotechnology.neu.edu/ConferenceProgram.pdf

[3] *Advances in Hole Injection Layer Technology to Accelerate Commercialization of Organic Light Emitting Diodes*, Plextronics, Inc. [www.plextronics.com]

[4] *AdaM Active Data Mover* and *Nomad Eyes Network* [www.tetradgroup.com]

[5] Duparré, J., Schreiber, P., Dannberg, P., Scharf, T., Pelli, P., Völkel, R., Herzig, H.-P., Brauer, A., Artificial compound eyes – different concepts and their application to ultra flat image acquisition sensors, *MOEMS and Miniaturized Systems IV*, A. El–Fatatry, ed., Proc. SPIE **5346**, 89–100 (2004)

[6] Völkel, R., Eisner, M., Weibel, K. J., Miniaturized Imaging Systems, *Microelectronic Engineering* 67–68, 461–472 (2003)

[7] Duparré, J., Schreiber, P., Matthes, A., Pshenay-Severin, E., Brauer, A., Tünneman, A., Microoptical Telescope Compound Eye, *Optics Express* **13**, No. 3, 890–903 (2005)