VAMP – A Vision Based Sensor Network for Health Care Hygiene

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Abstract – Adequate hand-washing has been shown to be a critical activity in preventing the transmission of infections such as MRSA in health-care environments. Hand-washing guidelines published by various health-care related institutions recommend a technique incorporating six hand-washing poses that ensure all areas of the hands are thoroughly cleaned. In this paper, an embedded wireless vision system (VAMP) capable of accurately monitoring hand-washing quality is presented. The VAMP system hardware consists of a low resolution CMOS image sensor and FPGA processor which are integrated with a microcontroller and ZigBee standard wireless transceiver to create a wireless sensor network (WSN) based vision system that can be retargeted at a variety of health care applications. The device captures and processes images locally in real-time, determines if hand-washing procedures have been correctly undertaken and then passes the resulting high-level data over a low-bandwidth wireless link. The paper outlines the hardware and software mechanisms of the VAMP system and illustrates that it offers an easy to integrate sensor solution to adequately monitor and improve hand hygiene quality. Future work to develop a miniaturized, low cost system capable of being integrated into everyday products is also discussed.

Keywords – Hand-washing, Intelligent Vision System, FPGA, CMOS Image Sensor, Wireless Sensor Network.

I. Introduction

According to the Health Service Executive (HSE) in Ireland and many other health-care institutions around the world, hand hygiene is the single most important intervention to prevent transmission of infection in health-care environments [1]. The cost of hospital acquired infections has been valued at €13 – 24 Billion in the EU [2] and $5 Billion in the US [3] annually. It is internationally recognized that hands should be washed adequately before direct contact with patients and after any activity or contact that contaminates the hands [4]. It has also been shown that the technique used is the most important element of the hand-washing procedure to ensure hands are thoroughly cleaned [5]. Several hand hygiene guidelines published show that correct hand-washing should include six different poses [6] as depicted in Figure 1.

Advances in CMOS technology over the past 20 years have enabled designers to develop miniaturized, low power, high resolution image sensors at a low cost. The ease at which CMOS sensors can be integrated with digital circuitry makes them a popular choice for use in the mobile phone camera and webcam markets. At the same time, the popularity of FPGA devices has seen a significant increase. This is due to their fast turnaround time, low start-up costs and ease of design. Increasing device densities have made large computational challenges feasible, allowing FPGAs to play a central processing role in system environments [7]. Unlike other sensing devices, image sensors generate large amounts of data due to the two-dimensional nature of their pixel array. Human analysis of raw image data can be ineffective for a wide variety of applications. By combining an image sensor with a processor, a high degree of intelligence can be added to a system. Local processing can be used to detect and track objects and extract high level information from their characteristics. Removing the need to transmit potentially irrelevant high density image data greatly reduces the bandwidth requirement of the system. The low bandwidth need of such a system makes it suitable to be integrated as part of a distributed wireless sensor network (WSN) where all system nodes connect with a single gateway node relaying relevant environmental events. WSNs are less intrusive than wired systems, simplifying the installation process of the system.

Depending on the image processing carried out; a vision based sensor network can be deployed to meet the requirements of a wide variety of application scenarios such as surveillance, environmental monitoring and smart meeting rooms [8]. In 2007, Hengstler et al. [9] developed a low power ARM7-based smart camera wireless node for applications in distributed intelligent surveillance. Vision algorithms to detect, track and acquire images of intruders in real-time were demonstrated. Over the last decade, several authors have addressed the issue of single hand gesture recognition [10] and in 2007 a PC based system for hand washing quality assessment based on six hand-washing poses was developed by Llorca et al. [11]. The

Fig. 1 Six poses from the hand-washing guidelines of the HPSC

system designed detects and tracks hand movements and classifies the motion carried out by performing the following steps:

- Skin Detection to locate hands
- Detection if hands are joined
- Region of interest (ROI) created around joined hands
- Analysis of hand motion within the ROI to produce a classification of the hand motion; e.g. Pose 1
- Classification of all motion to ensure adequate hand-washing has been achieved

In this paper an intelligent embedded vision system, VAMP comprising of a CMOS camera and FPGA processing node with Handle-C based algorithms is introduced as part of a distributed wireless sensor network with the aim of adequately monitoring hand-washing, based on image algorithms developed by Llorca [11].

This paper is organized as follows: Section 2 provides an overview of the VAMP system hardware and its architecture is discussed in detail. In Section 3 the software system comprising of the Handle-C based image processing algorithms is introduced. Section 4 details the integration and future deployment of the system. Finally, conclusions and future lines of research are presented in Section 5.

II. Hardware system architecture

The basic structure of the VAMP system node is shown in Figure 2. It can be broken into three main sections; CMOS image sensor, FPGA processor and micro-controller/Radio unit.

The CMOS image sensor chosen for the VAMP system is the OmniVision OV7649 Color CMOS CameraChip. The camera's low resolution (VGA/QVGA), adjustable sampling rate and sensor features meet all the specifications set by the PC based image algorithms. A dedicated CMOS camera interface PCB (see Figure 3) was designed to confirm compatibility with the image algorithms and to assist with image acquisition development. The camera sensor's low cost and efficient power consumption adds to it's suitability for incorporation in a final user product.

When designing the first VAMP system prototype it was essential to choose an FPGA with high processing capability to meet the potentially high demands of a wide range of image algorithms. For this reason, the Xilinx Virtex-4 LX160 device was chosen. It offers high density, high performance logic architecture, advanced system clock management, integrated RAM and a large number of block I/Os with design potential in many application areas. Before the design of a VAMP specific system PCB, the Celoxica RC340 Virtex-4 evaluation board was acquired. It combines the LX160 FPGA with a wide range of functionality giving users the ability to design Handle-C based system code. The RC340 was interfaced with the camera PCB, to assist in the development of the FPGA based image algorithms.

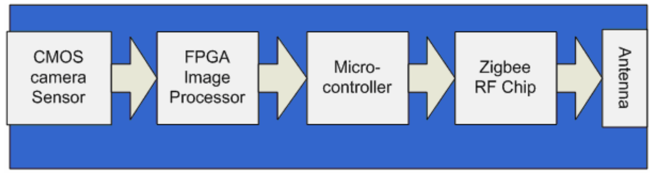

Fig. 2 VAMP system node block diagram

A low bandwidth, low power wireless transceiver is desirable for the VAMP system due to the minimal data bandwidth requirement of the system. ZigBee standard radios offer these features at a low cost. They also can easily be implemented on a microcontroller and support a number of different network topologies [12]. It was decided to use the Tyndall 25mm microcontroller/radio node layer developed in the Tyndall National Institute for the VAMP system network. The layer combines an Atmel ATmega128 microcontroller and an Ember EM2420 2.4GHz ZigBee standard RF transceiver. The Tyndall 25mm node is a modular based system which consists of a number of layers of different functionality that are stacked up on each other [13]. This unique design will allow for the addition of extra functionality to the VAMP system if required in the future.

The first system prototype combines the technologies summarized above with added functionality to produce an easy to use VAMP developmental platform. A detailed block diagram of the VAMP PCB architecture is shown in Figure 4. Included in the design is 72Mb of ZBT SRAM and 64Mb of non-volatile flash memory to meet any temporary frame buffering, image archival or algorithm needs of the system. Also included is 64Mb of configuration PROM memory for in-system programming when deployed in real-world environments. Other additions include a real time clock, UART communications and a high speed video

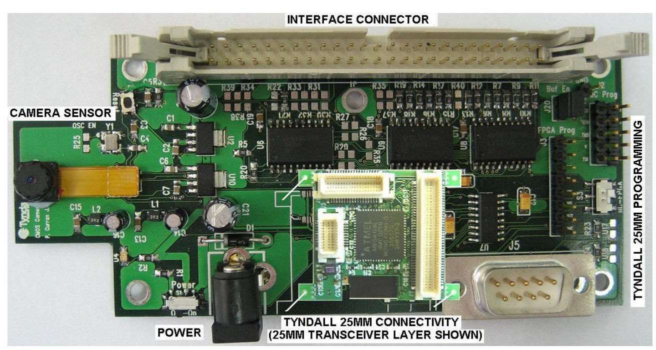

Fig. 3 CMOS camera interface PCB

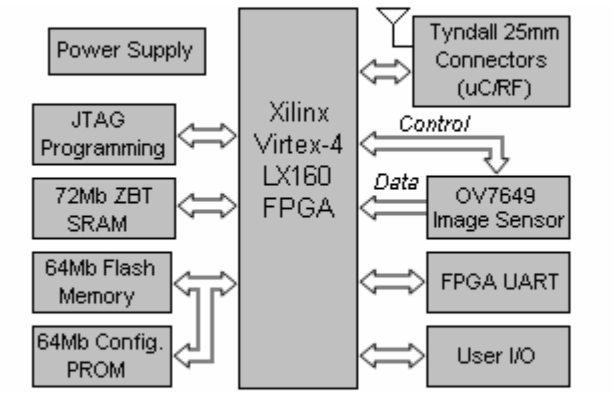

Fig. 4 Block diagram of the VAMP PCB architecture

DAC and VGA output port for system debugging. User interface functionality is included in the form of hand-washing pose display LEDs, an LCD screen and momentary push button contact switches.

The VAMP system PCB is currently in its manufacturing stage and once completed will have the functionality to host a wide variety of vision based applications that can be tested in real-world environments and can act as a stepping stone to a fully integrated miniaturized low cost product.

III. Software system

The image processing carried out on the FPGA is the key element in the effective operation of the VAMP system. The algorithms developed for this system are based on PC based algorithms as discussed in Section I. These were originally designed in a C code environment. For the efficient development of the FPGA based code it was decided to use the Handle-C programming language. Handle-C is a hardware description language in which programs are written in a conventional sequential format but are compiled into hardware images for use on FPGAs. It is essentially a subset of the C programming language and includes many libraries to assist in the development of image processing algorithms.

The original PC based algorithms were based on a support vector machine (SVM) classifier. Although this produced a very accurate result, it would not have been feasible to implement on an FPGA due to the number of support vectors required. A Fisher LDA classifier was developed in C code to overcome this and when tested on a range of varying scenarios it was shown to be very effective with accuracies of up to 96%.

The PC based algorithms process images frame by frame with each frame made up of 24-bit RGB pixels from real-time video. The FPGA based system firstly captures the image data in a YUV format from the camera module, frame by frame. This image data is then up-sampled and converted to RGB before being processed further. A block diagram summarizing the operation of the image algorithms is shown in Figure 5.

Two main strategies had to be considered before porting the image algorithms to Handle-C; processing the image data row by row or frame by frame as carried out on the PC based algorithms. Processing row by row is more efficient as many parallel and pipeline programming techniques could be used to speed up the algorithm performance [14]. However, the complexity in converting the algorithm would require large amounts of debugging. Frame by frame processing would use more of the available FPGA resources but conversion and debugging time would be greatly reduced. Based on these findings, it was decided to develop the Handle-C code, processing image data frame by frame.

When porting the algorithm to Handle-C it was important to consider the programming constrains of the compiler as well as the architecture constraints of the FPGA. Complex mathematical equations are completed in one clock cycle in a C environment. To meet this specification in Handle-C, the compiler will build a large combinational circuit on the FPGA, which introduces path delays when implemented in practice. By breaking complex equations into a number of smaller pipelined calculation steps this issue can be overcome. Other considerations include the removal of float point data-types from the code as they are not supported by Handle-C and efficiently setting the bit length of variables and array sizes to limit the amount of FPGA logic cell resources used.

The algorithms are in the final stages of the porting process and once completed, will be customized for the VAMP system prototype and will be tested in a variety of real-world environments.

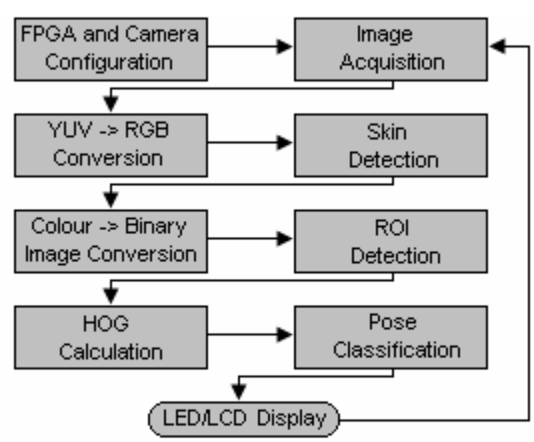

Fig. 5 Block diagram of the Handle-C algorithm operation

IV. System integration and deployment

The VAMP system prototype will operate as if it were a final fully functional product. A user will make contact with the device via a system input (e.g. push button) and the unit will wake up and signal the user to begin hand-washing. As the user completes each pose in the hand-washing procedure, pose display LEDs will light. When hand-washing is adequately completed, an added LED will illuminate confirming this. If the user has failed to carry out adequate hand-washing in a pre-determined time a “hand-washing not completed” LED will light. At this point, all high-level hand-washing data compiled on the FPGA will be passed to the microcontroller and combined with user data. This will be transmitted over the ZigBee standard network to the single gateway node for storage. Multiple VAMP units can be used in a single network.

The VAMP PCB is the size of a standard A5 page. It will be packaged in a similar sized custom made unit allowing for easy installation and with the user push switches, status and pose display LEDs and the LCD screen mounted externally. The unit will be powered from the mains supply in the first prototype. When deployed in a real-world environment, the VAMP system unit will be mounted above a mirror with the camera faced down on the sink. Additional lighting will be added if required for the successful operation of the system. Multiple units will be tested in different health-care scenarios to confirm adequate operation of the VAMP system.

V. Conclusions and future work

In this paper, a networked wireless vision system (VAMP) to monitor hand-washing quality was presented. The operation of the system is based on the detection of six hand-washing poses. VAMP is made up of a local system node and a gateway node and could be retargeted at a wide variety of applications. All processing is carried out locally and in real-time at the system node by Handle-C developed image algorithms stored on an FPGA. The resulting high-level hand-washing data is transmitted to the gateway node for record storage. The data could also be utilized for a wide variety of other fashions, such as providing records for use within Hazards Analysis and Critical Control Points (HACCP) controls. The system presented offers an easy to integrate, user friendly sensor solution to improve hand hygiene in health-care environments.

Future work can be split up into three sections. The first area that will be concentrated on will be optimizing the image algorithms to improve efficiency and reduce the amount of FPGA resources required by the system. User interaction with the system will be improved by introducing an RF ID tagging system into VAMP to recognize users. This can be incorporated via the Tyndall 25mm connectors. Finally a miniaturized hardware system will then be designed capable of being integrated into everyday products, with emphasis on reduced manufacturing costs and power consumption.

Acknowledgments

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References

1. SARI (2005) Guidelines for hand hygiene in Irish health care settings. HSE, Health Protection Surveillance Centre. ISBN-10:0-9540177-8-1
2. Suetens C (2005) What is the burden of health care associated infections in Europe? Eur J Public Health 15(1):36
3. Harrison P F, Lederberg J (1998) Antimicrobial Resistance: Issues and Options. The National Academies Press, USA. ISBN-10:0-309-06084-2
4. WHO (2002) Prevention of hospital-acquired infections, a practical guide, 2nd Edition. WHO/CDS/CSR/EPH/2002.12
5. Larson EL (1995) APIC guideline for handwashing and hand antisepsis in health care settings. Am J Infect Control 23(4):251-269
6. Royal College of Nursing (2005) Good practice in infection prevention and control – Guidance for nursing staff. RCN, London
7. Tessier R, Burleson W (2001) Reconfigurable computing for digital signal processing: A survey. J VLSI Sig Proc 28:7-27
8. Obraczka K et al. (2002) Managing the information flow in visual sensor networks. WPMC Proc. vol. 3, Int. Symposium on Wirel. Pers. Multimedia Commun., Honolulu, Hawaii, 2002, pp 1177-1181
9. Hengstler S, et al. (2007) MeseEye: A hybrid-resolution smart camera mote for applications in distributed intelligent surveillance. IPSN Proc. International Conference on Inf. Proc. Sens. N., Cambridge, USA, 2007, pp 360-369
10. Pavlovic V I et al. (1997) Visual interpretation of hand gestures for human-computer interaction: A review. IEEE T Pattern Anal 19(5):677-695
11. Llorca D F et al. (2007) A multi-class SVM classifier ensemble for automatic hand washing quality assessment. BMVC Proc. Brit Mach Vision Conference, Warwick, UK, 2007, Paper-223
12. ZigBee Alliance (2007) ZigBee Specification http://www.zigbee.org
13. O’Flynn B et al. (2005) The development of a novel miniaturized modular platform for wireless sensor networks. IPSN Proc. International Symposium on Inf. Proc. Sens. N., Los Angeles, USA, 2005, pp 370-375
14. Muthukumar V, Rao D V (2004) Image processing algorithms on reconfigurable architecture using Handle-C. DSD Proc. Euromicro Symposium on Digit. Syst. Des., Rennes, France, 2004, pp 218-226

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