See-through Passive Antiferroelectric Helmet-Mounted Liquid Crystal Display

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Abstract—Helmet-Mounted Miniature Information Display (HEMIND) is an IST EU project whose main purpose is to design, prototype and manufacture a helmet-mounted display system for firefighters. The display has been made of a high resolution, miniature, see-through, monochrome display. An autonomous, portable, computer system present images overlapped with the normal viewing field of the user. The images can be video images (thermal images, standard images) as well as data from sensors integrated in the clothes of the user or received through a radio-communication system.

The system is composed of Head Equipment (helmet, display, camera, viewer), Body Equipment (Control Unit and Interface Units) and Interconnect Equipment (Battery, Cabling).

Index Terms— Helmet-Mounted Display, Antiferroelectric liquid crystal, Passive Addressing

I. INTRODUCTION

HEMIND project has been carried out by a number of companies (SIDSA–Spain, KZPT–Poland, AMIS–Belgium), research centers (PIAP–Poland, IMEC–Belgium) and universities (Military U. of Technology–Warsaw, Polytechnic U. Madrid). The project aim was to develop helmet mounted displays (HMD) specifically designed to meet the operational requirements of firefighters [1]. The system includes a see-through display (a liquid crystal display in our case) equipped with the corresponding optics for near-to-eye operation, and attached to an infrared camera. At the same time, the display shall be able to show other critical information such as location, escape routes, and sensor readings. Therefore the system includes an interface unit, body equipment control and radio communication with the base station.

To overcome the problem of having a high resolution, low cost and low weight display in the viewer, passive antiferroelectric LCD technology has been used, as it is capable of providing high-resolution multiplexed video-rate images with gray scale [2-3]. As this technology is not currently under production, its implementation has required the development of a specific liquid crystal mixture, the

fabrication of the display, and the design of the driver ICs [3-4]. Development of a new antiferroelectric liquid crystal capable of operating in a broad temperature range opens the utilization of this technology in many applications where its intrinsic grayscale, image holding through a bias voltage, and fast switching time [5-8] can overcome the main drawback of this technology, i.e., relatively low contrast.

The actual display area is 24×18 mm with XGA resolution running at 60Hz video frequency in dual-scan mode (Fig. 1). Being a passive display, the glass plates had to be enlarged to

Fig. 1. Display dimensions considering fan-out and chip-on-glass drivers. Microscopic view of a section of the antiferroelectric display fully switched

allow room for the rows and columns fan-out to the chip-on-glass drivers. Column drivers have been obtained from Claris. Row drivers have been developed within HEMIND project by IMEC [9]. These drivers had to be tailored for the application, since the display addressing requires the generation of 7 voltage levels up to 50 volts. In a typical configuration, 4 column drivers (8 in dual-scan mode) and 2 row drivers are mounted onto the glass plates. Taking into account the pitch of the drivers' contacts and the required edge connections, the actual size of the display results considerably larger (80×64 mm). This brings a collateral problem since the display must fit inside the helmet (any alternative with the system outside the helmet is not feasible in firefighter's actual working conditions).

II. SYSTEM DESCRIPTION

The HEMIND helmet system consists of the following subsystems: Head Equipment (helmet, display, camera and viewer), Body Equipment (Control Unit and Interface Units) and Interconnect Equipment. The following paragraphs focus on the display and optics system with associated electronics, though the remaining subsystems are commented as well.

A. Display

According to the initial specifications of distance to the eye and field of view, the display size was fixed to be about 2 inch diagonal. Other requirements were high resolution (XGA), grayscale images and video rate frequency. The specific performance required for the display should be handled by using multistable antiferroelectric liquid crystal, able to bear analogue grayscale in highly multiplexable passive display, such liquid crystal is an innovation in the present display technology as the suppression of the active matrix in the

Fig. 2. Top: The addressing waveform. Bottom: a multiplexed liquid crystal display.

display is cost-effective and simplifies manufacturing.

Antiferroelectrics are a specific kind of smectic liquid crystals. The most relevant members of this family for display application are ferroelectrics, antiferroelectrics and V-shape smectic liquid crystals [10]. Antiferroelectric liquid crystal (AFLC) displays shows fast switching time, they are monostable in the absence of the electric field and they can be stabilized at any transmission level by means of constant holding voltage, therefore they being effectively multistable developing an analog grayscale whose dynamic range is affordable with standard electronics.

AFLC switching is produced between states whose director is parallel to the outer cell plate (so called in-plane switching IPS). IPS displays behave as linear retarder plate, the phase delay induced in the incoming light depending on the display thickness. Therefore the thickness should be adjusted whitening the manufacturing parameters, typically about 1.5 μm . Our proposal waveform to drive the display consist of selection pulse, a bias region where a constant holding voltage keeps the pixel gray level, and a short counter pulse (well) followed by reset pulse[11]. Passive multiplexing is performed by sequentially scanning the display rows, while data for each row are written in the columns during their corresponding slot times (Fig. 2). The slot time for a fully multiplexed XGA display at 60 Hz video rate is about 18 μs (distributing the 16.6 ms framerate between 768 rows). This slot time is inconveniently short, since the LC switching would require extremely high selection voltage. It is possible to split longitudinally the display by dividing the columns, effectively working as two separate displays multiplexed at the same time, with column data being fed from both sides. This so-called dual-scan mode, doubles the slot time to a more reasonable 36 μs . With this slot, selection voltages of the selected AFLC materials is below 40 V, well within the specifications of the row drivers.

B. Passive matrix addressing

Another important part of helmet development has been the development of required driver ICs to drive the new antiferroelectric displays. The specifications of column drivers, including voltage range, could be met with

Fig. 3. Row Driver

commercial products (Claris). Row drivers, however, had to be designed and fabricated within the project. The architecture of the custom row and column driver is shown in (Fig. 3). Every row output is connected to high voltage multiplex that can switch between 7 different high voltage levels (up to ± 50 V).

The high voltages needed for the row waveform meant that a row driver had to be developed. The interface board is designed around this chip set, with the necessary interconnections to the LCD and the external controller hardware.

C. IR Camera and Body equipment control unit

The system has been tested with an infrared camera attached to the helmet. As the display resolution is higher than the available resolutions in commercial IR cameras, some “scaling” of the image (image processing) must be done by the Control Unit in order to present in the display the right image, at the right size, and in the right place (overlapping closely the real world image). The display may show additional information near the edges, such as alarms from integrated sensors (temperature, toxic atmosphere, lost radio connection, low battery, low air reserve, etc.) as well as simple messages from the external radio link.

The Interface Unit can be used for inserting these “alarms” or “informative signals” in the periphery of the display, to pass information to the firefighter about the status of a variety of external systems and devices out of the scope of this project.

The Interface Unit also has the capability of processing other input signals and sending warning messages to the external control center, such as the level of the oxygen tanks, a too high ambient temperature, or the presence of toxic gases.

The body control unit hosts the processor controlling the display and communicating with the Interface Unit. It also hosts the software required to control all the system and some kind of “keyboard” capable of being activated using protective gloves.

Fig. 4 Optics system prototype

Fig.5 optic system and display between helmet and gas mask

D. Optics

The purpose of the optics system is to bring the image of the LCD attached to the helmet to the bearer's eye in a see-through optical configuration. The actual distance between the eye pupil and the display is a few centimeters. It is impossible for the naked eye to focus at such a short distance. Even if it were able to focus, the eye accommodation would hinder the observation of the outer scene. The solution is to use an optical system that creates a virtual image of the display located at longer distance. In our optical system, the bearer's eye sees the real scene overlapped with a virtual monochrome image far enough (4 m) to avoid eye accommodation.

Such a long distance brings some collateral problems. To achieve a nearly perfect overlap between the IR image generated by the camera and the outer scene, only minute deformations of the image can be tolerated. The issue has been solved by using aspheric optics, specifically design for this project.

A second problem arises from the size of the optical system itself and the display within it. The specifications indicate that the firefighter may wear a gas-mask inside the helmet. Therefore the display and the optics system have to be fitted between the helmet visor and the gas mask, outside the bearer's field of view to allow the see-through condition. Either a half-plated mirror or a dichroic filter should be the only optic element in the bearer's sight, thus bringing to the eye overlapped images of the display and the landscape.

The optics system developed in HEMIND (Fig. 4) allows the display to be positioned in a nearly vertical plane to save space. The system is located over the bearer's forehead (Fig. 5). The backlight consists of a green LED (Nichia NSPGF50S) and a commercial collimator. The output aspheric lens has been designed within the project; it displays a virtual image of the LCD at 4 m with a 30° diagonal field of view (FOV). The FOV is limited by the distance between the eye and the output beamsplitter (37 mm), which is determined by the gas-mask.

III. CONCLUSION

Hemind mounted display described in this paper implemented a new multistable antiferroelectric liquid crystal display able to bear analogue grayscale in highly multiplexable (optical memory) passive displays. The display and the optical system, along with the remaining external units, are presently installed in a helmet prototype that is being tested under working conditions. The prototype can be considered state-of-the-art within the field of professional helmets, and has evident applications in many different professional areas.

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