

# Low-Power LCD Display Systems

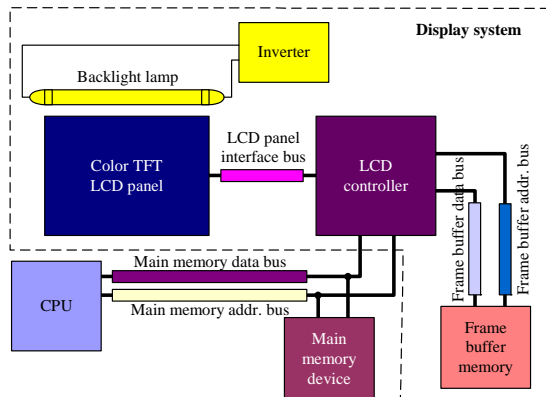
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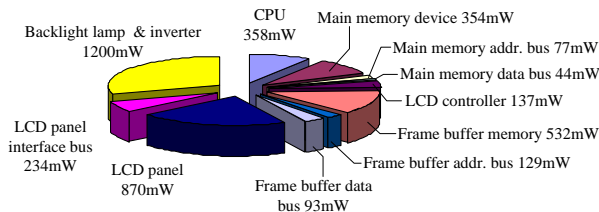
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**Supporting paper: [3]**

## 1. INTRODUCTION

Despite the limited power available in a battery-operated mobile embedded system, its display must have an enough resolution and sufficient color depth to support quality graphical user interfaces and multimedia applications. An LCD (Liquid Crystal Display) is a standard display device, and a color TFT (Thin-Film Transistor) LCD is common even in a low-cost equipment. An LCD display system is composed of an LCD panel, a frame buffer memory, an LCD controller, and a backlight inverter and lamp, as shown in Figure 1. High-resolution, high-color LCDs require large LCD panels, high-wattage backlight lamps and large-capacity frame buffer memories, which together lead to high power consumption.



**Figure 1. Block diagram of a mobile embedded system with a high-quality LCD display.**



**Figure 2. Power contribution of each system component with an MPEG-4 player running.**

Figure 2 shows where power goes when we run an MPEG-4 player on a popular mobile embedded system [1]. The CPU and the memory are in power-down mode during the slack time, but the display components are always active mode, for as long as the

display is turned on. This makes the LCD backlight the dominant power consumer, with the LCD panel and the frame buffer coming the second and third. An MPEG-4 player requires a lot of computing. Interactive applications such as a document viewer or a word processor, an even higher portion of the energy will be consumed by the display system.

In the dissertation, we will present a fully integrated framework for reducing the power consumption of the type of display system shown in Figure 1. Many techniques have been suggested for saving display power, and each aimed at a different display component: the backlight system [1, 2, 3, 5], the LCD panel [6], the frame buffer and its associated buses [1, 4], and the LCD panel interface bus [1]. Our proposed framework will consider the dependency between several low-power techniques, user's preferences, and current system context. Within this framework, we aim to optimize the display power consumption, while still satisfying QoS (Quality of Service) requirements.

## 2. LOW-POWER LCD DISPLAY TECHNIQUES

In this section, we summarize what has been done to reduce the power consumption of each display component. We have introduced several low-power LCD display techniques [1, 2, 3, 4] within a system-level approach. We accurately characterized the energy consumption at the component level and minimized the energy consumption of each component without appreciable display quality degradation. There is plenty of current research on low-power display systems with many power-saving techniques for proposed display systems [5, 6].

Dynamic luminance scaling (DLS) [2] of the backlight, with appropriate image compensation, was introduced early, because backlight systems dominate the power requirement. DLS keeps the perceived intensity or contrast of the image as close as possible to the original while achieving significant power reduction from the backlight system. DLS compromises between the quality of an image and the backlight power consumption, which fulfills a large variety of user's preferences in power-aware multimedia applications. The first DLS implementation with a color TFT LCD panel and a CCFL (Cold Cathode Fluorescent Lamp) backlight system was recently demonstrated [2]. Because the CCFL backlight usually responds slowly to the input changes for luminance control, we have proposed a feedback control circuit that enables the backlight luminance to change fast enough to support movie streams. DLS saves 20% to 80% of the power consumption of the backlight system while keeping the degradation of image quality within bounds.

We have extended DLS to cope with popular transmissive LCD panels, which operate both in the transmissive mode with a

backlight and in the reflective mode without a backlight, depending on the remaining battery energy and the ambient luminance. Our extended DLS (EDLS) system [3] compensates for loss of brightness when there is a rich or moderate power budget, and for loss of contrast when the power budget is low. In developing the EDLS system, we have pursued an application-transparent approach that intercepts the frame buffer contents and performs on-the-fly image compensation using additional hardware integrated into the LCD controller. This pure-hardware EDLS implementation has perfect application transparency, and we expect that this will contribute to the wide adoption of DLS because the need to modify existing applications limited the scope of use for DLS [2]. The proposed EDLS system gives an average backlight power saving of 25% for still and moving images.

Frame buffer compression [4] has also been used to reduce the power consumption of a frame buffer memory and its associated buses. LCD controllers periodically refresh their display at 60Hz, or an even higher sweep rate, and the frame buffer is therefore very active. Frame buffer compression reduces the activity of the frame buffer and thus its power consumption. The compression algorithm that we use is based on run-length encoding for on-the-fly lossless compression, and imposes a negligible burden in resources and time. We have also developed an adaptive and incremental re-compression scheme to accommodate frequent partial frame buffer updates efficiently. We save from 30% to 90% frame buffer activity on average for various mobile applications. The implementation of compression scheme consumes 30mW more power and 10% more silicon space than a conventional LCD controller without frame buffer compression, but the power saved in the frame buffer memory is up to 400mW.

Yet more techniques have been proposed to optimize the display power consumption. Dynamic color depth control [1] modifies the pixel organization in the frame buffer, which enables the half of the frame buffer memory devices power-down mode at the cost of a decreased color depth. Dynamic color depth control achieves an energy saving from the frame buffer. Variable duty ratio refresh [1] reduces the duty ratio of refresh cycles as far as possible if the time constant of the storage capacitor of a sub-pixel on the TFT LCD panel is higher than the refresh period, saving power in the frame buffer and the LCD panel interface bus. Other groups have been working on backlight autoregulation [5], which adaptively dims the backlight in response to changes in the ambient luminance, and a dark window optimization [6] which modifies the windowing environment to allow changes to the brightness and color of areas of the screen that are not of current interest to the user. This saves power in Organic LED display panels.

### 3. CONCLUSIONS AND ONGOING WORKS

Many low-power LCD display techniques have been proposed: DLS, EDLS, frame buffer compression, dynamic color depth control, variable duty ratio refresh, backlight autoregulation and dark window optimization. Each of the techniques saves the power consumption of the display system by reducing the activity of the corresponding components such as the backlight luminance, the color depth, the refresh duty ratio, and the pixel brightness.

We are currently working on a new frame buffer compression scheme that achieves more effective on-the-fly compression for

diverse screen images using a limited-size code book. We expect the new compression scheme to be more robust to exhibit better performance, and to save more power than our earlier compression scheme [4].

There are many techniques available for low-power display systems, and we need to choose those that are most appropriate. For example, both frame buffer compression and dynamic color depth control aim at the same objective: reducing the power consumption from the frame buffer. But they cannot both be applied at the same time, and so we have to select one. The user may be willing to allow some decrease in color depth in exchange for higher contrast in a document viewer, where image legibility is the most important QoS requirement, and dynamic color depth control can meet user's preferences. But if a photo image viewer is running, then image fidelity should be preserved, and we should adopt frame buffer compression.

Our ultimate goal is a complete framework that accommodates most of the power-reduction techniques that have been proposed for display systems. This framework will consider the dependency between several techniques, user's preferences and the current system context. It will then select the most appropriate techniques to satisfy the QoS requirement as well as the power requirement. We expect that this framework will conform to the MPEG-21 DIA standard by utilizing the *Usage Environment Description Tools* [7].

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