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7

# A Camera-Based Energy Management of Computer Displays and TV sets

Vasily G. Moshnyaga
*Fukuoka University*
*Japan*

## 1. Introduction

With increase in image quality and screen sizes, the energy consumption of computer displays and television sets has significantly grown. In a typical personal computer or PC, display accounts for 30%~50% of the total PC energy consumption [Mahesri 2005, Robertson 2002]. For instance, typical 19 inch LCD monitor, such as Sony SDM-S93 (1280x1024 pixels), burns in active mode 50W or almost 38% of the total desktop system power (130W). With large popularity of video and gaming applications, LCD makers are being called on to cut power consumption while providing better images. Rapid utilization of multiple displays -- each consuming tens of watts -- throughout homes, offices and buildings increases cost and environmental impact of energy consumption significantly. Although most PC displays support power management, new robust methods are needed for evolving display usage scenarios.

For TV sets, the quest for efficient display energy management is more severe, because modern TVs have much bigger screens than computer displays and therefore consume more power. Although the LCD TVs are more efficient than their cathode-ray tubes (or CRT) TVs, recently emerged plasma television sets are twice as bigger and about four times more energy than their cathode-ray tube equivalents [Coughlan, 2006]. A 50-inch flat-screen plasma HDTV now burns over 500Watts of power [Plasma TV, 2006]; consuming almost the same amount of energy as dishwasher or in-room air-conditioner. The problem however does not relate only to plasma television sets. The LCD TV sets also consume a lot. A typical 42" LCD TV takes 169-250Watts of power per each hour [TV Power Consumption, 2008]. According to Nielsen Media Research Inc. [Nielsen 2009] over 99% of all households in US have TV sets, with 2.24 TVs per household in average. Since TV is ON for almost 5 hours in an average US home a day [Television & Health], it has become one of the largest energy consumers. Due to emerging problems of global warming and fossil fuel shortage, reducing TV energy is very important.

Up to the date, reducing energy consumption of LCD displays has been tackled mainly through system and circuit optimizations, which either ignore the user, assuming fixed and stable demands on system operation or rely on very simplified policies, which eventually lead to large energy losses. Generally, there are two sources of energy losses in a device: *intrinsic* losses and the *user-related* losses. The intrinsic energy losses are caused by the engineering design, technology and materials used in construction of the device. For example, a plasma TV intrinsically dissipates more energy than a LCD TV, etc. The user-

related losses are associated with varying and inefficient device usage. Keeping a TV ON when nobody watches it, for example, causes energy loss associated with bad device usage.
Existing energy management policies are device centric; that is they either ignore the user, assuming unchangeable operational environment for the device or rely on very simplified polices. Take a TV for example. Take a TV for example. A variety of methods has been proposed to reduce energy consumption of TVs. Majority of them, however, target the intrinsic energy losses, without considering the viewer. As a result, the television sets produce bright and high quality pictures independently whether there is any viewer or not. According to [Gram-Hansen, 2003], the energy consumption of consumer electronic devices can differ by a factor of two due to usage. Some experts estimate that 26% - 36% of the total domestic energy consumption are losses related to unreasonable usage of appliances [Elias 2007]. Clearly, in order to reduce the losses, we must make the device energy management user-centric, i.e. adaptable to the varying user behavior. No energy should ever be spent uselessly.
In this chapter we present a new approach to LCD display and TV set energy management, which unlike existing methods employs a video camera to bind the display power state to the actual user's attention. We discuss implementation of this novel approach and show the results of its experimental evaluation.
The chapter is organized as follows. In the next section we survey related research. Section 3 describes the proposed camera-based display energy management approach. Section 4 presents implementation features for PC display and TV set. Section 5 summarizes our findings and outlines work for the future.

## 2. Related research

The core technology to manage power consumption of display in modern personal computers is Advanced Configuration and Power Interface (or ACPI in short) developed by HP, Intel, Microsoft, Phoenix, and Toshiba. The OS-based ACPI specifies one or more power states (e.g. standby, sustain, etc.) that are intermediate between *on* and *off* turning the display to low power state after a specified period of inactivity on mouse and/or keyboard. Each power state corresponds to proper level of display brightness and power consumption. The main problem with ACPI is that it strongly depends on inactivity intervals, either set as default or by the user. From one hand, if the inactivity intervals are improperly short, e.g. 1 or 2 minutes, the ACPI can be quite troublesome by shutting the display off when it must be on. From another hand, if the inactivity intervals are set to be long, the ACPI efficiency decreases. Because modifying the intervals requires system setting, most users however never adjust the power management of their PCs for fear that it will impede performance [Fujitsu-Siemens]. Those who do the adjustment, usually assign long intervals. HP inspected 183,000 monitors worldwide and found that almost a third was not set to take advantage of the energy saving features. Just enabling these features after 20 minutes of inactivity can save up to 381 kWh for a monitor per year [Hewlett-Packard 2006]. Evidently, to prevent such a problem the PC energy management must employ more efficient user monitoring.
Several techniques have been proposed to improve presence detection of computer users. Extending touch-pad function beyond pointer movement to provide user-presence

[1] Apple PCs employ power management technology that is distinct from but similar to ACPI (see [Nordman 1996], [Nordman 1997] for more details

identification is proposed in [Park, 1999]. [Dai 2003] suggests using thermal sensors placed around display screen to detect user's presence by comparing temperature fluctuation the sensors during a sample interval. When user is present, the temperature fluctuation is consistent with a normal fluctuation pattern of human breathing.

TV sets also employ screen brightness dimming technologies for energy saving. Nowadays TV viewers can modify the screen brightness level by selecting one of three operation modes: the "standard mode" delivers the highest level of brightness; the "saving mode" refers to the dimmed screen and "no brightness mode" reflects the dark screen. The brightness level in the saving mode can also be changed. Sensing light is already a feature of many TVs to enable dimming based on ambient light level. However, unless the light is changed or the viewer changes the mode, the TV maintains same brightness.

Many efforts have been put recently on brightness/contrast adjustment techniques to lower display energy consumption in active mode. The reason is that transmissive and transflective color TFT LCD panels [Sharp 2002] do not illuminate itself but filter a backlight, the primary source of display energy dissipation. Because simply dimming the backlight degrades the display visibility, Choi, et al [Choi 2002] proposed to maintain brightness or contrast of the LCD panel when the backlight is dimmed down. To reduce the average energy demands of the backlight, Gatti, et al [Gatti 2002] suggested the backlight auto regulation scheme. Cheng and Pedram [Cheng 2004] showed that a concurrent brightness and contrast scaling (CBCS) technique further enhances image fidelity with a dim backlight, and thus saves an extra power. Chang, et al [Chang 2005] introduced a dynamic luminance scaling or DLS technique that dimmed the backlight while allowing more light to pass through the screen panel to compensate for the loss of brightness in the original image. Shim, et al [Shim 2004] combined the DLS technique with dynamic contrast enhancement and applied it for transflective TFT LCD panels. Pasricha, et al [Pasricha 2004] presented an adaptive middleware-based technique to optimize backlight power when playing streaming video. Iranli, et al [Iranli 2006] presented HVS-aware dynamic backlight scaling in TFT LCD. A modification of the LCD panel to permit zoned backlighting has been discussed in [Flin 1999]. There is also a variety of techniques for automated adjustment of brightness in high dynamic range panoramic images, e.g. [Pattanai 2000], [Tumblin 1999]. These techniques dynamically brighten or darken image regions depending on the scene content and average local luminance.

Despite differences, the proposed brightness and/or contrast adjustment techniques have one feature in common. Namely, they work independently on the viewer attention. While the techniques are able to decrease the TV energy consumption in active mode, they can not change the modes. So TV screen remains active even if nobody watches it. Similarly to computer users, majority of TV viewers do not change brightness or power mode for energy savings, fearing that it affects picture quality. Besides, viewers usually watch TV while doing other activities: reading books, working on PC, preparing food, chatting with friends, etc. According to statistics, a TV is ON for almost 5 hours in an average US home a day [3]. As Kaiser Family Foundation [Generation M2, 2010] reports, 39% of 8-18 year olds in US say they keep TV on while doing other things "most of the time"; 29% say they do so "some of the time." In other words, a TV frequently wastes energy for producing high quality pictures when nobody watching them.

Leading TV produces have recently started to embed "user sensors" into TV sets in order adjust power consumption to the user behavior. For example, the VIERA® plasma TV from Panasonic senses the user through the remote controller. If the time from the last use of remote controller exceeds a pre-defined time interval (e.g. 1, 2 or 3 hours), the TV automatically powers off. The latest Bravia® HDTV from Sony incorporates an infra-red motion sensor, which switches the TV off when no motion has been detected in front of it over a period of time (e.g. 5 min, 30 min or 1 hour) pre-set by the user. Also Hitachi and Toshiba use hand gesture sensors to control TV.

Sensing the viewer explicitly (through fingers, hands or body motion) has several problems: it is either incorrect (a moving dog or a tree in the window can keep the TV on) or troublesome, i.e. requires the user either to push the remote control or move in front of the screen frequently or to enlarge the allowed duration of inactivity interval to prevent shutting the TV down. Also, because modern PCs monitor the user' fingers not eyes, they can not distinguish whether the user looks at the screen or not. Therefore, they may either switch the screen off inappropriately, i.e. when someone looks at the screen without pressing the keys, or lose energy by staying in active mode while idling. We claim that ignorance of the viewer's attention is the main cause of the user-related energy losses of existing displays in PCs and TVs. While the display operation mode must depend on the viewer, existing displays, up to our knowledge, do not take the viewer's focus into account. We propose a method which can solve this problem.

## 3. The proposed display energy management technology

The main goal of our approach is to increase the energy efficiency of display by enabling it to "watch" its viewer and lower down the display power whenever the viewer is detracted from the screen. We assume that the screen of computer display or TV is enabled with a video camera. This can be a special camera embedded in display for viewer monitoring, an infra-red camera or a general purpose video camera (e.g. SONY VAIO visual communication camera) connected via USB port for video capture, conferencing, etc. The camera is located at the top of display or TV. When a viewer looks at the screen, it faces the camera frontally. Also we assume that computer display and TV have a number of backlight intensity levels with the highest level corresponding to the largest power consumption and the lowest level to the smallest power, respectively. The highest level of backlight intensity is enabled either initially or whenever the user looks at the screen. In all cases we assume that the viewer monitoring mode is optional to the user.

The idea behind our display energy management is simple. When the user of PC or TV looks at screen, the screen is kept active in "power-up" mode to provide the best visibility. If the user detracts his/her attention from the screen, the screen is dimed off to decrease energy consumption. Finally, if nobody looks at the screen for long time or disappears from the camera's range, the screen enters the "sleep" mode or is turned off to save energy.

In order to make the technology effective, the camera based viewer tracking system must satisfy a number of requirements, such as initialization simplicity, be non-intrusive, support unrestricted head movements, real time operation and low energy consumption. The latter requirement is especially important for battery operated personal computers because it keeps the PC battery lifetime and weight reasonable. Majority of currently available viewer tracking systems, unfortunately, do not satisfy these requirements making energy management a real challenge. For instance, some systems need calibration procedures; the others require users to wear head-mounted gears (a hat or helmet or glasses on which camera is mounted) or restrict head positions within a quite narrow area. Those systems which meet the requirements are unfortunately very energy consuming [Ji 2002], [Baluja 1994], [Ohno 2003], [Theocharides 2004], [Park 2005], [Kawato 2005].

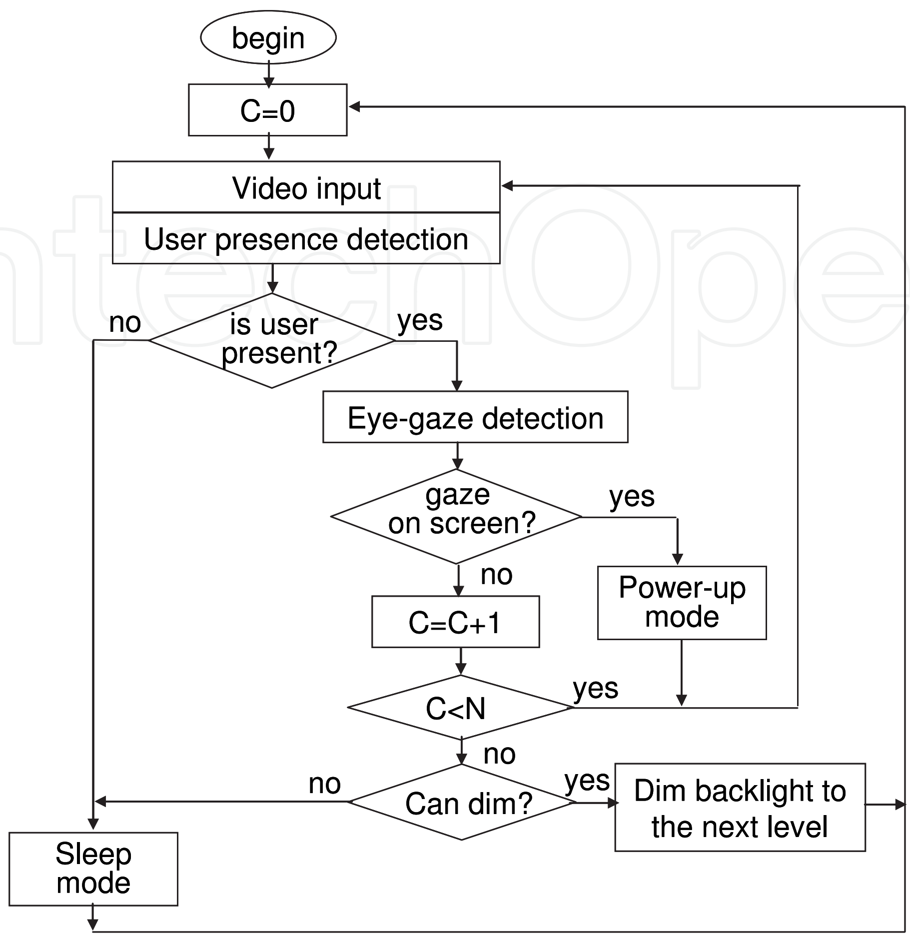



Fig. 1. The flowchart of the proposed camera-based computer display energy management

Below we present techniques which ensure real-time camera-based energy management with low-energy overhead. Although the same methodology can be used for tracking viewers of computer display and TV set, we optimize the techniques by the application to reduce the energy overhead.

### 3.1 The camera based computer PC display energy management

Figure 1 shows the flowchart of our camera-based computer display energy management. Here, C counts the number of consecutive image frames in which the user's gaze is off the screen. We assume that the camera is located at the top of display. If no user is detected in the N consecutive video frames, the display is turned to the sleep mode. Otherwise, the technology tracks the user's eye-gaze. If the gaze has been off the screen for more than N consecutive frames, the backlight luminance is dimmed down to the next level. Any on-screen gaze reactivates the initial backlight luminance by moving the display onto power up mode. However, if no on-screen gaze has been detected for more than N frames and the backlight luminance has already been lowest, the display enters the sleep mode. Returning back from sleep mode is done automatically whenever the user gaze is back on screen. The user may also switch the display OFF whenever he or she wishes. Re-activating the screen from the OFF state requires pushing the ON button.

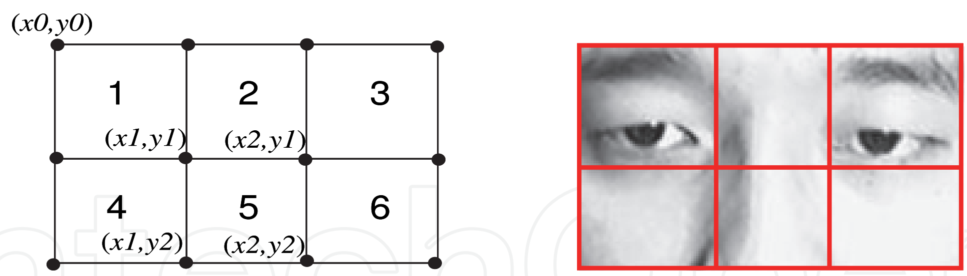


Fig. 2. An illustration of the SSR filter

### 3.1.1 User presence detection

The goal of this task is to determine from the camera (or CMOS sensor) readings whether or not the user is currently present in front of display. To detect the user's presence in front of the display, we first localize the face search by applying background subtraction and skin-color segmentation to the RGB representation of input image. The skin is defined by the following criteria [Douchamps 2002]: 0.55<R<0.85, 1.15<R/G<1.19, 1.15<R/B<1.5 and 0.6<(R+G+B)<1.8.

To accelerate the face-area extraction, we use two filters. The first one limits the size of the head in reasonable range. The second one verifies that the face contains a minimum of 25% of skin colored pixels. Thus, if the total number of pixels in the derived face area exceeds the threshold (W), the user is assumed present.

### 3.1.2 Eye-gaze detection

The eye-gaze detector implements the algorithm proposed by [Kawato 2005], which scans the Six Segment Rectangular filter (SSR) over the integral representation [Viola 2001] input image. to define the Between The Eyes (BTE) point of human face (see Fig.2) and then searches the regions 1 and 3 from the left and right side of the BTE point to locate the eyes. The algorithm does not depend on illumination, face occlusion, eye closure. It is more stable, robust and less complex than the other eye-tracking formulations. However, it is still very computationally demanding. In a quest to locate all faces (without restriction on face size, motion and rotation) the algorithm repeats scan six times over the whole image frame performing over 28 Million operations, such as addition or subtraction per frame (640x480 pixels frame size). Though such a full search might be necessary in some applications, it seems redundant when tracking eyes of the PC user.

In our eye-tracking application we can assume that:

1. The target object is a single PC user. The user sits in front of PC at a relatively close distance (50-70cm).
2. The user's motion is slow relatively to the frame rate.
3. The background is stable and constant.

Based on these assumptions, we apply the following optimizations to reduce eye-tracking complexity:

a. single SSR filter scan;
b. fixed SSR filter size;
c. three pixel displacement of the SSR filter during the scan;
d. low frame processing rate (5-10 fps);

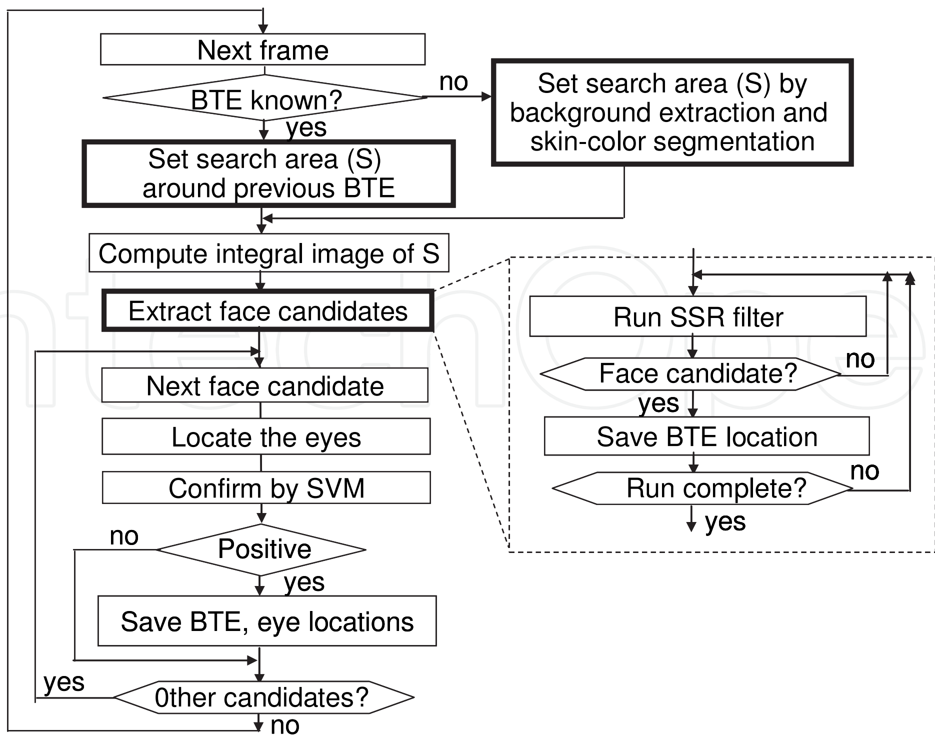



Fig. 3. The modified eye-tracking algorithm

As our study shows [Yamamoto 2009], such enhancements reduce computational complexity considerably without affecting the quality of the results.

Fig.3 shows the modified algorithm. For the first frame or any frame in which the search for BTE candidate was unsuccessful, we search the image area reduced by background and skin-color extraction; otherwise the search is restricted to a small area (S) of ±8 pixels around the BTE point. For the chosen area, the algorithm first computes the integral image and then scans it by the Six Segment Region filter (SSR) to select the BTE candidate. If the BTE candidate is found, the system uses the BTE as a starting point to locate eyes. If eyes have been detected, the user is assumed to be looking at screen; else it is not. If no face candidate has been found for N consecutive frames, the user is considered not present in front of the display.

The BTE search is organized as follows. The green component of the search area is transformed to integral image representation [Viola 2001] and scanned by the six-segment rectangular (SSR) filter (Fig.2). At each location, the SSR filter compares the integral sums of the segments as follows: At each location, the SSR filter compares the integral sums of the segments as follows:

$$Sum\,(1) < Sum\,(2) \;\;\&\;\; Sum\,(1) < Sum\,(4) \tag{1}$$

$$Sum\,(3) < Sum\,(2) \;\;\&\;\; Sum\,(3) < Sum\,(6) \tag{2}$$

If the above criteria (1) are satisfied, the SSR is considered to be a candidate for the BTE pattern (i.e. face candidate) and two local minimum (i.e. dark) points each are extracted from the regions 1 and 3 of the SSR for left and right eyes, respectively.

In the search for eyes, we ignore 2 pixels at the boarder of the regions to avoid effects of eyebrows, hair and beard. Also, because the eyebrows have almost the same grey level as the eyes, the search starts from the lowest positions of regions 1 and 3.

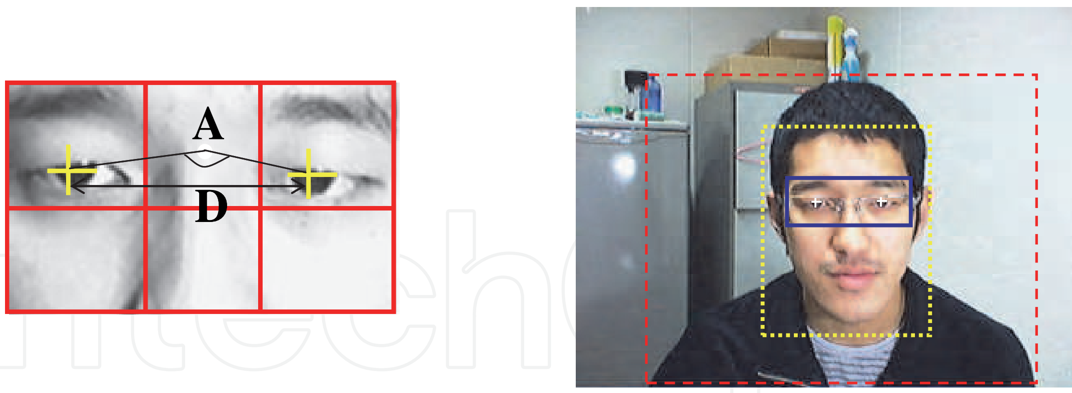



Fig. 4. An illustration of the eye detection heuristics (left) and the search area reduction

The eye localization procedure is organized as a scan over the green plane representation of regions 1 and 3 for a continuous segment of dark pixels (i.e. whose value is lower than the threshold k). As in [Kawato 2000], we assume that eyes are located if the distance between the located eyes (*D*) and the angle (*A*) at the center point of the BTE area 2 (see Fig.4, left) satisfy the following:

$$30 < D < 42 \quad \& \quad 115° < A < 180° \tag{3}$$

If both eyes are detected, the user's gaze is considered to be on screen. Otherwise, it is assumed to be off the screen. The eye positions found in the current frame are then used to reduce complexity of processing the successive frames. Since the face/eye motion of computer user is slow in practical circumstances, the search in the next frame is limited to a small region, which spans by 8 pixels in vertical and horizontal direction around the eye points of the current frame.
Fig. 4(right) demonstrates the search area reduction by our algorithm: dashed line shows the area defined by background extraction; dotted line depicts the area obtained by skin-color segmentation; the plain (dark line) shows the area around the previous BTE point; white crosses show the computed locations of eyes.
If for any frame, the user gaze is detected to be on screen, the backlight luminance is set-up to the highest level by resetting the backlight voltage to the initial value. If the gaze has been detected off the screen for N consecutive frames, the backlight voltage is reduced to the next level to dim the backlight luminance down. If the lowest level of the backlight voltage supply has been reached and the user still is not found in the camera readings, the system switches the display off to save energy.

### 3.1.3 Implementation

Fig.5 outlines the block-diagram of the proposed computer display power management system. The user tracking unit receives an RGB color image and outputs two logic signals, $u_1$,$u_0$. If the user is detected in the image, the signal $u_0$ is set to 1; otherwise it is 0. The zero value of $u_0$ enforces the voltage converter to shrink the backlight supply voltage to 0 Volts, dimming the display off. If the eye-gaze detector determines that the user looks at screen, it sets $u_1$=1. When both $u_0$ and $u_1$ are 1, the display operates as usual. If the user's gaze has been off the screen for more than *N* consecutive frames, $u_1$ becomes 0. If $u_0$=1 and $u_1$=0, the input voltage ($V_b$) of the high-voltage inverter is decreased by $\Delta V$. This voltage drop lowers backlight luminance and so shrinks the power consumption of the display. Any on-screen

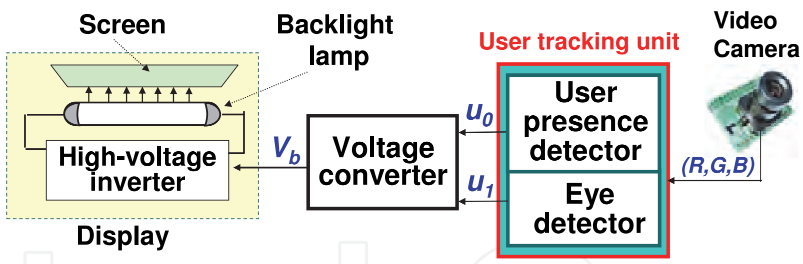



Fig. 5. Block diagram of the camera-based display energy management system

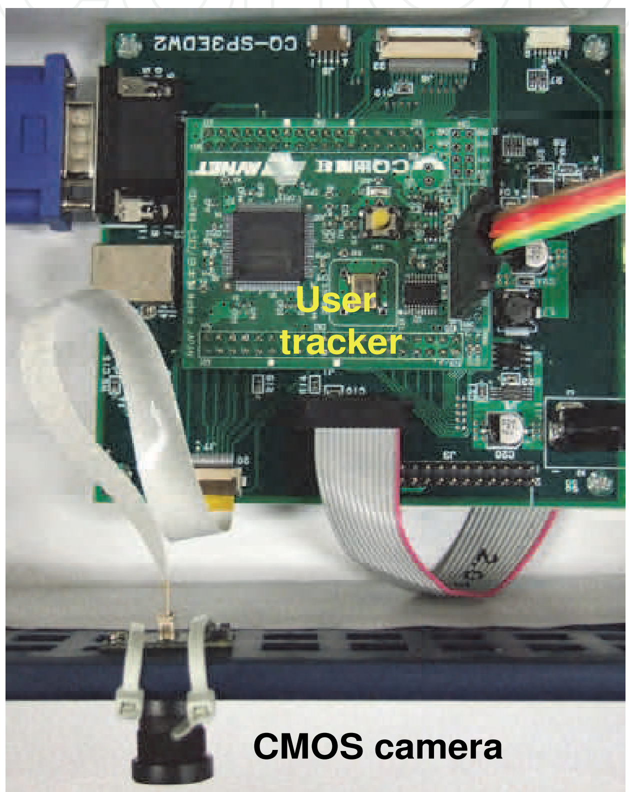



Fig. 6. The user-tracking hardware

gaze in this low power mode reactivates the initial backlight luminance and moves the display onto normal mode. However, if no on-screen gaze has been detected for *N* consecutive frames and the backlight luminance has already reached the lowest level, the display is turned onto sleep mode.

We implemented the system in hardware (see [Moshnyaga 2009] for details). Fig.6 illustrates the hardware design of the user tracking unit. The design was synthesized in Verilog HDL using Synopsis Design Compiler and realized on a single FPGA (Xilinx XC3S250E) board. The board is connected to VGA CMOS camera, through parallel I/O interface. Table 1 summarizes parameters of the FPGA design. The user tracking unit operates at 48MHz frequency using 3.3V external voltage and provides user presence detection at 20fps rate. Due to capacity limitations of the on-chip SRAM memory, input images were 160x120 pixels in size. The SSR filter was 30x20 pixels in size. The total power consumption of the gaze detector design was 150mW, which is 35 times less than software implementation of the user presence detector on desktop PC (Pentium4@2.53GHz) [Moshnyaga 2005].

| Parameter | Value |
|---|---|
| System clock frequency | 48MHz |
| External voltage | 3.0V |
| Internal voltage | 1.2V |
| System gate count | 250000 |
| Logic cell count | 18508 |
| Memory size | 216Kb |
| Frame size (pixels) | 160x120 |
| Detection rate | 20fps |
| Power | 150mW |

Table 1. FPGA design parameters

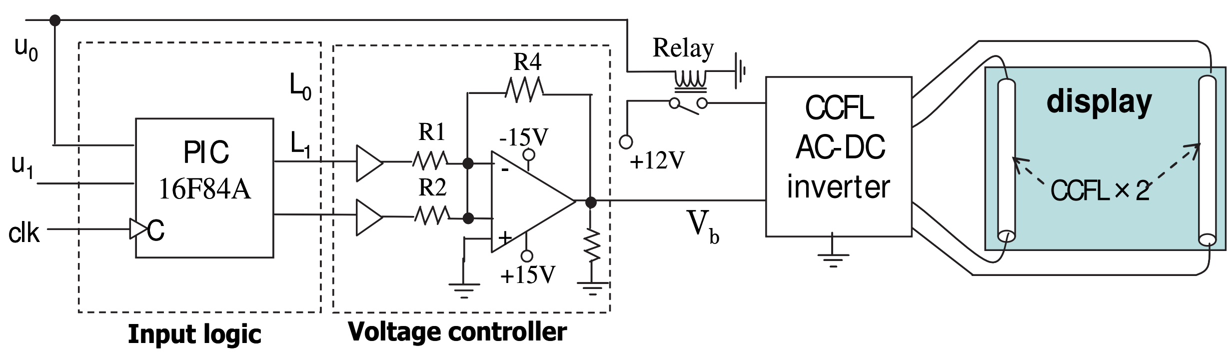
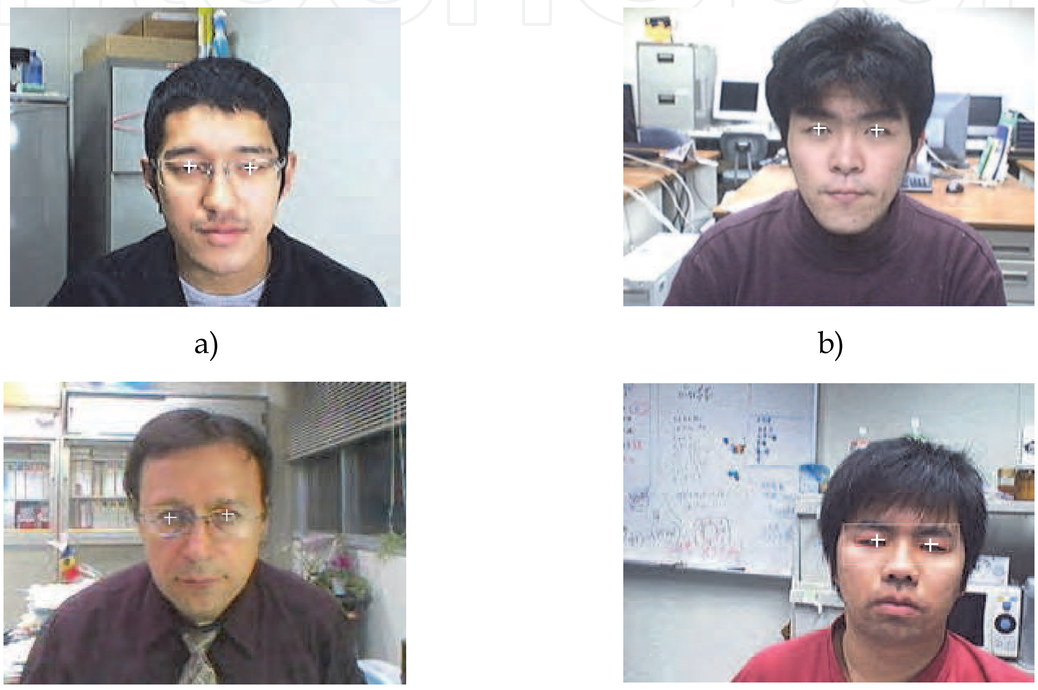



Fig. 7. The modified voltage converter

Next, to change the display brightness dynamically, we modified the voltage converter by adding the input logic, the voltage controller, and a relay, as shown in Fig.7. In TFT LCD displays, the Pulse Width Modulation (PWM) scheme links brightness of the cold cathode fluorescent lamps (CCFL) to the input voltage, Vb, of the CCFL AC-DC inverter. Usually, the display brightness is the highest when Vb=0 and the lowest when $V_b$=5V. In our design, the voltage $V_b$ is controlled by two inputs ($u_0$,$u_1$) whose levels are defined by the eye-gaze detector (see fig.5). When $u_0$=0, the relay disconnects the 12V power supply to the display switching it OFF. Turning the display ON automatically sets $u_0$ to 1, which enforces +12V voltage supply to display. When u0=1, the display power consumption is controlled by the output ($V_b$) of the voltage controller. Namely, when $u_1$=1, the counter (*cnt*) nulls outputs $L_1$,$L_2$ setting $V_b$ to 0V. When $u_1$=0, the counter increments its state with each new rise of signal *clk*, thus setting the voltage converter to increment its output $V_b$ by approximately 0.7V. Table 2 outlines the display voltage control and the power consumption at the corresponding four voltage levels. As it clearly shows, changing the brightness leads to large savings of display power.

| u1 u0 | Vb(V) | Brightness | Power (W) |
|---|---|---|---|
| 1 1 | 0 | bright | 34.03 |
| 1 0 | 1.2 | Level 1 | 27.43 |
| 1 0 | 2.4 | Level 2 | 22.21 |
| 1 0 | 3.6 | Level 3 | 17.54 |
| 1 0 | 4.8 | Level 4 | 14.62 |
| 0 - | - | OFF | 0.01 |

Table 2. Display voltage control parameters



a) b) c) d)

Fig. 8. Examples of true detection

### 3.1.4 Evaluation

To evaluate accuracy of the gaze detector, we ran four different tests each of each conducted by different users. The users were free to look at the camera/display, read from the materials on the table, type text, wear eyeglasses, move gesticulate or even leave the PC whenever wanted. Fig.8 illustrates the detection results on 4 images. The + marks depict positions where the system assumes the eyes to be. As we see, even though the lighting conditions of faces vary, the results are correct. Ordinary pairs of glasses (see Fig.8) have no bad effect on the performance for frontal faces. In some face orientations, however, the frame of pair of glasses can hide a part of eye ball, causing the system to loose the eye. Or sometimes it takes eyebrow or hair as an eye and tracks it in the following frames.

Table 3 summarizes the results. Here, the second column depicts the total number of frames considered in the test; columns marked by ‘True’ and ‘False’ reflect the number of true and false detections, respectively; the *Accuracy* column shows the ratio of true decisions to the

| Test | Frames | True | False | Accuracy (%) |
|---|---|---|---|---|
| 1 | 151 | 133 | 18 | 88 |
| 2 | 240 | 214 | 26 | 89 |
| 3 | 100 | 90 | 10 | 90 |
| 4 | 180 | 152 | 28 | 84 |
| Average | 167 | 147 | 20 | 88 |

Table 3. Results of evaluation on test sequences

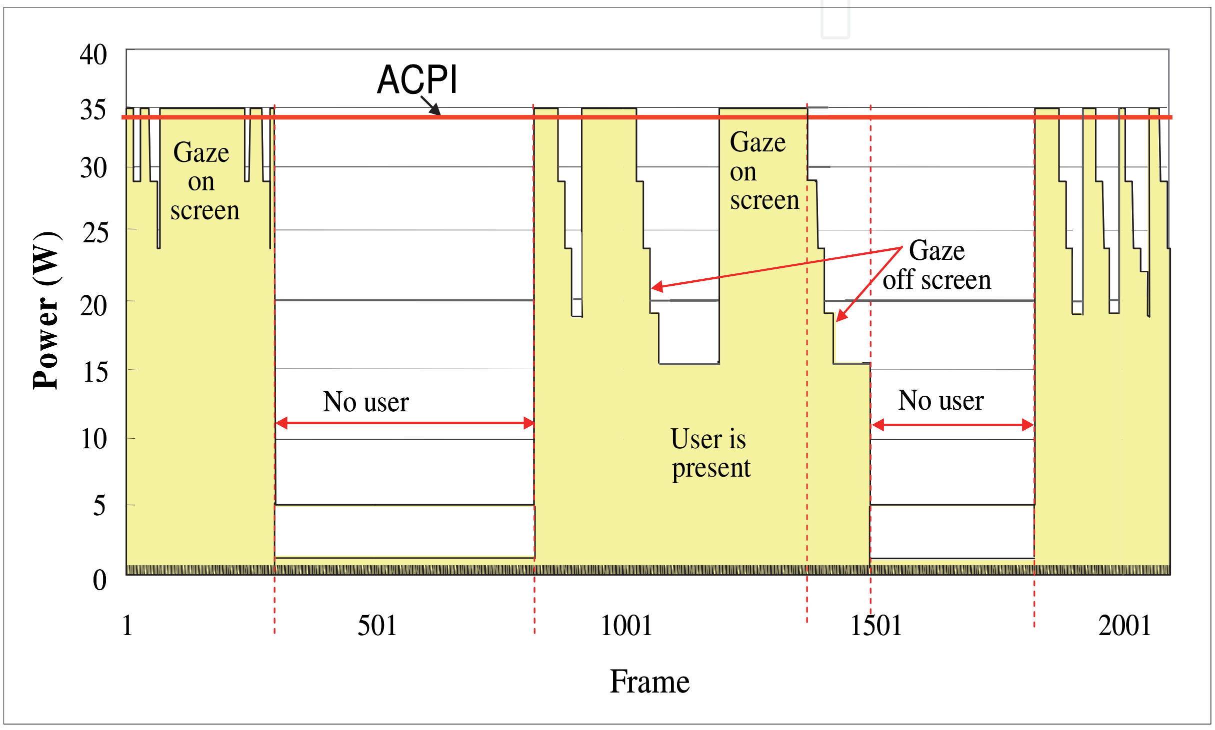



Fig. 9. Power consumption vs. image frame for the tested display

total number of all decisions made. As the tests showed, the eye detection and tracking accuracy of proposed hardware is quite high (88% on average).
Next, we estimated the energy efficiency of the proposed system by measuring the total power consumption taken from the wall by the system itself and the 17" IO-DATA TFT LCD display (35W on peak, eight different levels of screen brightness) controlled by the system. Fig.9 profiles the results measured per frame on a 100sec (2000frames) long test. In the test, the user was present in front of the display (frames 1-299, 819-1491, 1823-2001); moved a little from the display but still present in the camera view (frames 1300 to 1491); and stepped away from the PC disappearing from the camera (frames 300-818, 1492-1822). The system was set to step down from the current power level if the eye-gaze off the screen was continuously detected for more than 15 frames (i.e. almost 1 sec). The ACPI line shows the power consumption level ensured by the conventional ACPI power management.
We observe that our technology is very effective. It changes the display power accordingly to the user behavior; dimming the display when the user gaze is off the screen and illuminating the screen (by elevated power) when the user looks on it. Changing the

Fig. 10. Screenshots of display and corresponding power consumption: when the user looks at screen, the screen is bright (power: 35W); else the screen is dimmed (power: 15.6W)

brightness from one power level to another in our system takes only 20ms, which is unobservable for the user. Fig. 10 shows the brightness of the screenshots and the corresponding power consumption level (see the figures which are displayed on the down-right corner of the pictures; the second row from the bottom shows the power).

The total power overhead of the system is 960mW. Even though the system takes a little more power than ACPI (see horizontal line in Fig.9) in active mode on this short test, it saves 36% of the total energy consumed by the display. In environments when users frequently detract their attention from the screen or leave computers unattended (e.g. school, university, office) the energy savings could be significant.

### 3.2 The camera based TV energy management

#### 3.2.1 An overview

The methodology used for camera-based TV energy management is similar to that discussed in Section 3.1 with the difference that for TV it monitors multiple viewers simultaneously.

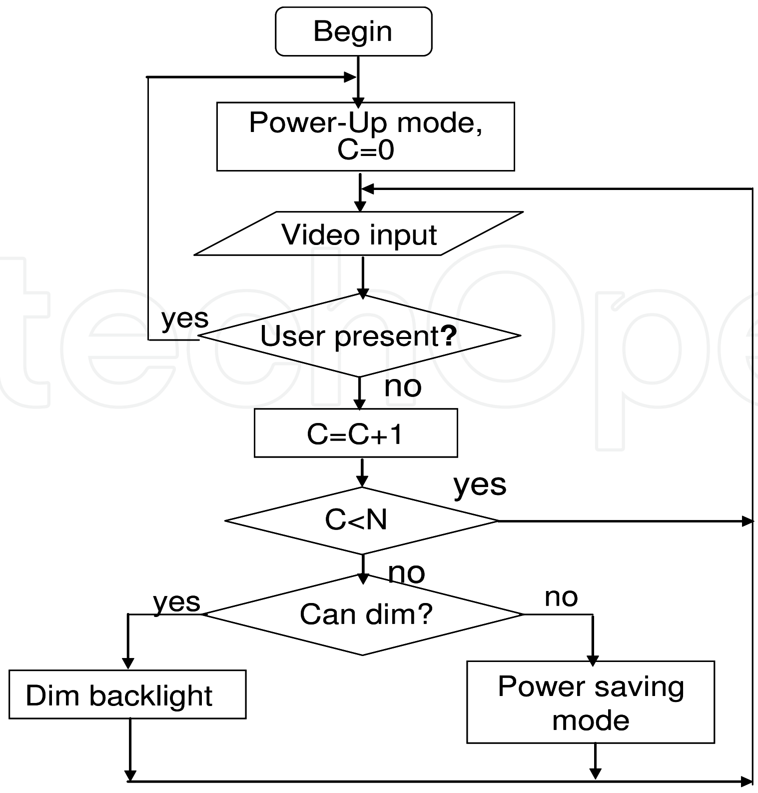



Fig. 11. Flowchart of the camera-based TV energy management

Also, because TV screens are much larger than PC displays, the TV viewers can be on a far distance from camera than the PC users. As result, detecting gaze of TV viewers correctly based on a typical CMOS sensor or web camera actually becomes impossible. Therefore for TV, we track faces (no eyes), assuming that viewers, who watch TV, face the screen (and camera) frontally. Besides, people sometime watch TV in darkness when ordinary CMOS image sensors are almost useless. In such conditions, the only device which can be used is an infra-red camera or IR-vision sensor.
Fig. 11 shows the flowchart of the proposed TV energy management. Here C denotes a counter and N is a given threshold. By default, the TV screen is bright providing the best picture quality. Every image frame captured by the camera is scanned to detect a human face. If neither motion nor human face is detected (i.e. no viewer is present or present but not looking at the TV screen) in N consecutive frames, the screen is dimmed to a lower level of screen brightness. If the screen brightness has already reached the lowest level and can not be dimmed anymore while no human face has been detected for N consecutive frames, the screen is turned to the sleep mode (i.e. black screen) while the audio system (i.e. sound) is kept ON. Any on-screen face reactivates the initial backlight luminance by moving the screen onto the normal mode.

### 3.2.1 Implementation and evaluation

To detect a human face we developed in Linux OS a face-detection software by using open-source C-language image processing library "Open-CV" [OpenCV] from Intel. The program detects faces based on a boosted cascade of simple Haar-like features, proposed by Viola and Jones [Viola, 2001]. It provides correct detection of human faces located up to 4 meters away from the camera and ±40 degrees in horizontal and vertical directions.

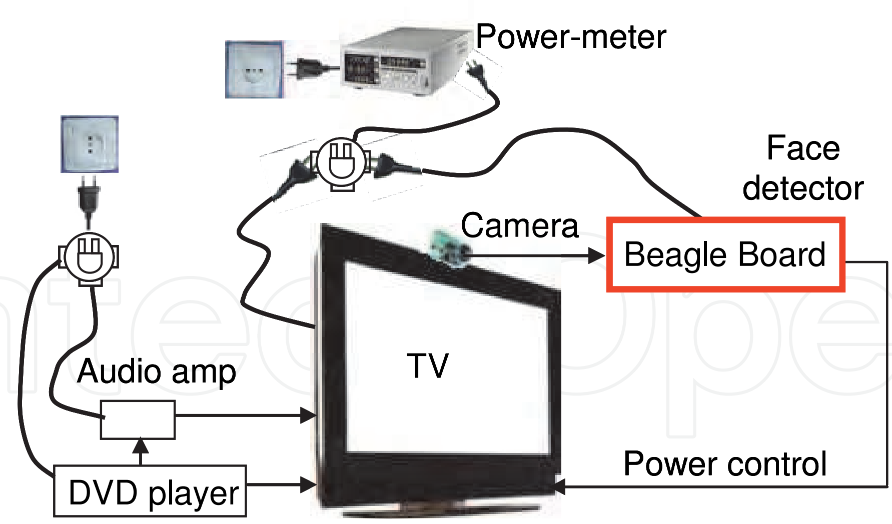



Fig. 12. Experimental system of camera-based TV management

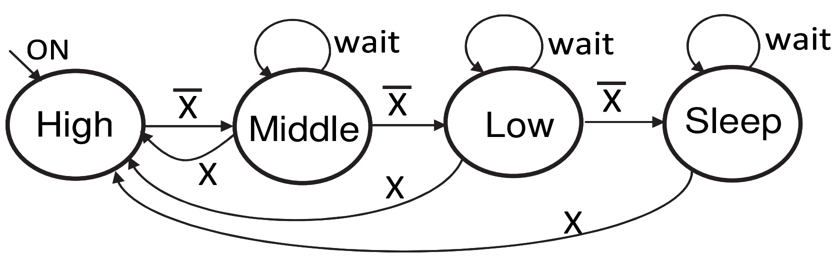



Fig. 13. TV State Transition Diagram

To evaluate the efficiency of the proposed approach, we developed prototype camera-based TV management system illustrated in Fig.12. The core of the system is ARM-based BEAGLE-Board, which runs face-detection and TV power control in Ubuntu OS. The board is connected through RS-232C serial port to 42in NEC LCD V421 TV and through parallel port to video camera (640x480 pixel resolution, 30fps) placed at the top of the TV. Images captured by the camera are processed in real time to detect whether there is at least one viewer of the TV screen or not. Based on the detection results, the board generates commands that change the TV brightness and power or even set the TV off. To facilitate experimental measurement, we connect the TV to a DVD player which runs a tested video film. Additionally, to keep the TV's audio system ON while screen is OFF (such mode unfortunately is not supported by the TV), we use a separate audio amplifier connected to the TV.

Fig.13 shows the state transition diagram of the TV control implemented by the board. Here, X corresponds to a positive result of face detection; 'High', 'Middle' and 'Low' denote states corresponding to the brightness levels 100, 50 and 0, respectively (see Fig.14); 'Sleep' represents the state with dark screen (backlight off) and audio ON. The wait time in each state was set to 5 sec in our system. The transition time from a higher brightness state to a lower brightness state was a few milliseconds; the time of High-brightness state reactivation from the Sleep state was also 5 sec. According to our measurement, the Beagle-Board consumed 4W of power when running the face detection. The camera consumed 0.5W. Therefore the overhead of our software based implementation of face detection was less than 5Watt.

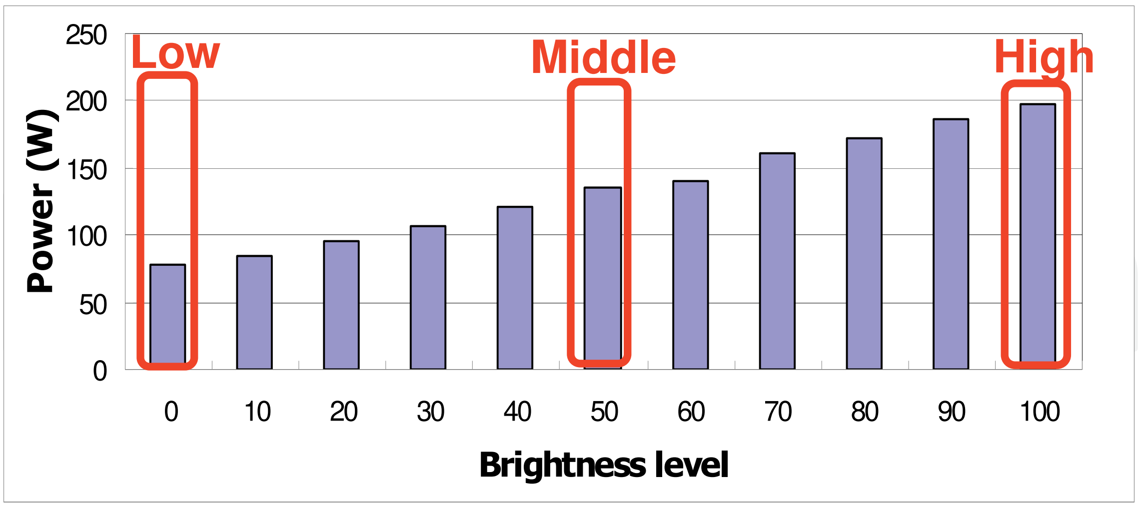



Fig. 14. The dependency of TV power consumption on brightness. The brightness levels corresponding to selected power states are shown in red.

To evaluate energy efficiency of the proposed approach, we performed a number of tests, each of each differed by the number of viewers, viewer behavior, the duration of time the TV was viewed, the activities simultaneously done while watching TV, etc. (More details about the tests can be found in [Moshnyaga 2011]). In all these tests, we measured the total energy taken from the wall by all components of our system (TV, Beagle-board and camera) and compared it to the energy consumed by TV in the motion-based screen-off mode, which was set to the shortest (5min) period of inactivity.

The results reveal that the proposed energy management technology performs better then Motion-Based Power Management (MBPM) when the TV users are either frequently detracted from the screen by other activities or use it mainly for listening (as radio), not watching. Even with the shortest time setting, MBPM technique was unable to save energy most of the time because of the viewer's motion. In contrast, the energy saving achieved by our method are high (up to 50-90%). Obviously, the savings depend on the user behavior.

If the viewer is not disrupted from TV by other activities, the proposed method adds 5 Watt per hour overhead to the TV energy consumption. However, in comparison to TV power of 200W it is quite small. Moreover, whenever a 200W TV is left unwatched for longer than 1.2 min per hour, the proposed camera-based energy management works better than existing motion-based user sensing. Fig.15 shows the screenshots of TV screen, camera readings on PC display and the power meter: when there is a TV viewer, the screen is in High Brightness mode (power: 206.4W); else the screen is dimmed and eventually enters sleep mode– bottom picture (power: 5.2W).

Fig.16 exemplifies the TV power consumption during typical 2 hours long TV watching by two users. The power bursts in the figure correspond to the screen activation when the viewer returns his gaze to the screen. Notice, the MBPM takes around 200W all the time independently of the viewer behavior. Even though the power savings achieved by our CBPM system in comparison to MBPM on this test were not as impressive as on the other tests there was quite large: 29%.

Fig. 15. Screenshots of TV and corresponding power consumption: when viewers looks at screen, the screen is bright (power: 206.4W); else the screen is dimmed (power: 5.2W)

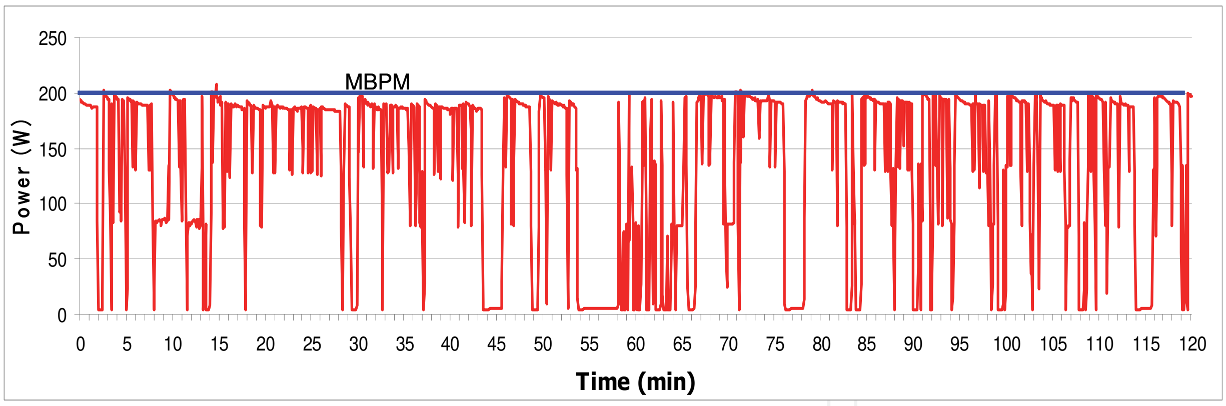



Fig. 16. A profile of power consumed by the proposed camera based power management (CPBM) system in comparison to motion based power management (MBPM) during 2 hours long typical TV watching.

## 4. Conclusion

In this paper we presented a new technology for energy management in computer display and TV set based on camera-based viewer monitoring. For the PC display, we track eyes of the user, while for the TV set -- faces of its viewers, keeping the screen active only when someone looks at it. Experiments showed that the technology saves more energy than existing schemes monitoring viewers behavior in real-time with high accuracy. The current implementation of PC display energy management in FPGA consumes only 1W of power while implementation of camera-based TV energy management in low-power embedded system (Beagle-Board) takes only 5W.

A possible solution to reduce power overhead could be in designing a custom LSI chip for viewer detection, similarly to those implemented in photo camera. This will push the energy overhead to the mW level.

The research presented here is a work in progress and the list of things to improve it is long. In the current work on PC energy management, we restricted ourselves to a simple case of a singular user. However, when talking about the user-gaze monitoring in general, some critical issues arise. For instance, how to handle more than PC user? The main PC user might not look at screen while the others do. Concerning this point, we believe that a feasible solution is to keep the display active while there is someone looking at the screen.

The TV viewer monitoring also has several challenging issues. First, the viewers can be positioned quite far from the TV set. Second, the viewers can watch TV when laying on a bed or a sofa, so the viewer's face can rotate on a large angle. Third, the face illumination condition may change from a very bright to a complete darkness. In these conditions, the correct real-time face monitoring with low-energy overhead becomes really difficult. Our future study will cover the use of IR-camera, impact of face orientation, face color and other issues.

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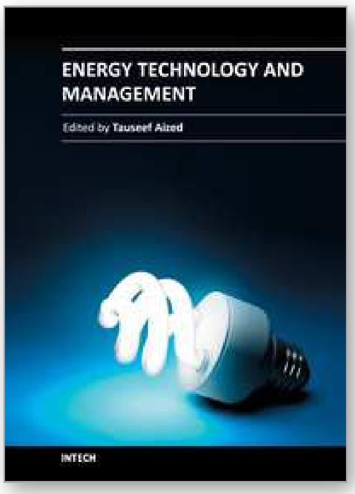


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The civilization of present age is predominantly dependent on energy resources and their utilization. Almost every human activity in todayâ€™s life needs one or other form of energy. As worldâ€™s energy resources are not unlimited, it is extremely important to use energy efficiently. Both energy related technological issues and policy and planning paradigms are highly needed to effectively exploit and utilize energy resources. This book covers topics, ranging from technology to policy, relevant to efficient energy utilization. Those academic and practitioners who have background knowledge of energy issues can take benefit from this book.

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