An FPGA-Based Tiled Display System for a Wearable Display

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ABSTRACT
We developed an FPGA-based tiled display system as a wearable display. Four 15.6-inch displays are arranged in a grid and formed a single display which has an input of HDMI signal. FPGAs are used to divide and scale the image into four LCD panels. This system can be used as a wearable display, such as a digital sandwich man. A smartphone which supports MHL output can be connected to the system, and users can modify the contents of the display on the fly. The merit of using hardware is that displays can be synchronized enough to play movies on them; No screen tearing occurs. The system consumes lower power than a single display with equivalent size.

KEYWORDS
FPGA, Tiled display, Wearable display

1 INTRODUCTION
A tiled display system (or display wall) is one of the major solutions to construct a single display with a reasonable cost. Such system is often used for digital signage, scientific visualization, immersive video for virtual reality, and so on. It is basically composed of many displays specially mounted in a grid, controlling software/hardware, and an input device. There are several methods to achieve a single display with many screens. SAGE2 [1] is a special software to control many screens which are connected to PCs. Client software can access a tiled display via network, and many clients can share the same big display. MovieTile [2] is also a software to control many displays which are composed of smartphones or tablets to support a free-shape tiled display. FPGAs (Field Programmable Gate Arrays) are often used to divide input image into several screens by hardware [3, 4].

The merit of using hardware is that screen tearing does not occur even when a movie file is played on it. Screen tearing is a visual artifact that appears when different frames of the movie are displayed in a single image. If vertical refresh timing of two displays are not synchronized, different frames would be shown at the same time in some area. Then we can recognize a torn look since edge of objects do not line up. Methods by software cannot completely prevent from screen tearing since each display panel is controlled by its own hardware and synchronization within one frame of time is impossible. Normally, one frame takes 1/60 seconds when a normal LCD (Liquid Crystal Display) panel is used.

Another merit of using hardware for a tiled display is that any input device can be supported when it supports HDMI (High-Definition Multimedia Interface). HDMI is one of the common interfaces of sending video stream, and many devices including digital camera, camcoder, smartphone, tablet, notebook PC, compact computer like Raspberry Pi, etc. can be used to connect the display. Most smartphones do not have HDMI connector, but they can output HDMI signal if they support MHL (Mobile High-definition Link). Method using a software needs a controlling computer for both of

Figure 1. Mobile tiled display system as a digital sandwich man
server and client sides. LCD monitors need to be connected to server computers and only intelligent clients, such as a smartphone, tablet, and PC, can connect to the server. Therefore, hardware control is more universal compared with the implementation by software.

In this paper, we report a mobile tiled display with FPGAs which can be used as a wearable display. One can hang it in front or back and the screen of his smartphone can be shown on it as a digital sandwich man (see Figure 1). It consumes lower power than a single display. The paper is organized as follows. Section 2 describes the details of our mobile tiled display. Section 3 explains future plan of extension. Section 4 summarizes our paper.

2 MOBILE TILED DISPLAY

In this section, a detailed description of a mobile tiled display is shown. First, system overview is explained in section 2.1. How to rotate the input image is explained in section 2.2. Then internal functions of FPGAs are described in section 2.3. Finally, difference between tiled and single displays is compared in section 2.4.
connections among four LCD panels, three FP-GAs, and four mobile batteries. One mobile battery, SONY CP-F10LSAVP [7], has 10,000 mAh capacity with two 5V outputs. One output of each battery is connected to an LCD panel, and three outputs among four remaining outputs are connected to FPGAs. The remaining output is used for charging a smartphone or a tablet.

Figure 4a shows the physical layout of components inside of the system. FPGAs and batteries are located between two wooden panels. Each LCD panel is hanged by a special hook provided with the LCD panel. Figure 4b shows the side-view of two wooden panels. The whole system is attached to a mounting carrier (see figure 5) to hang in front or back of a man/woman. We changed the belt upside down to hang the panel perpendicularly.

2.2 Rotation of Image

One problem of connecting a mobile device (smartphone or tablet) is the orientation of the image via HDMI output. PC displays are usually landscape, which means the width is larger than height. However, displays in mobile devices are portrait, which means height is larger than width. When a mobile device is in landscape style (see figure 6a), a PC display is fully filled with an image. On the other hand, when the device is in portrait style (figure 6b), only one-third part of the display is filled with the image since the output image is portrait. The effective resolution becomes very low because more than two-third part is wasted in black.

We tested several smartphones and found that some of them can output HDMI signal always in landscape even when the device itself is in portrait style (figure 6c). An application to lock the orientation (portrait or landscape) must be activated to enable this even when a special device is used. By using the special smartphone, we can get a portrait image on a tiled display as shown in figure 2.

2.3 Function of FPGA

Three FPGAs have two different functions. The Main FPGA in Figure 2 receives the HDMI signal from a user device, such as a smartphone or a tablet. Then it copies the video signal to two HDMI outputs. A Sub FPGA enlarges a specific region of the input video to each of HDMI outputs. Upper Sub FPGA also need to rotate the output by 180 degree.

2.3.1 Main FPGA

Figure 7 shows the block diagram of the Main FPGA. It has following functions.

- Input of HDMI signal with EDID function

The Main FPGA receives the HDMI signal. At the same time, it sends an EDID (Extended Display Identification Data) signal to the input device to support non PC device. The problem is that only specific resolution is recognized when a smartphone or tablet is connected.
When a smartphone is directly connected to the LCD panel, the resolution was recognized as $640 \times 480$ pixels, which is much coarser than the native resolution. However, when the smartphone is connected to a Full HD LCD panel, the resolution was $1280 \times 720$. Therefore, we made a special EDID logic in Main FPGA to pretend as a display with $1280 \times 720$ resolution. If a PC is used as an input device, there is no problem since one can modify the resolution by hand.

- Remove sound information from HDMI signal

As similar to the above, there is another problem when non-PC device is connected to. Sound information inside the HDMI signal caused a problem when processing the video signal in the logic of the FPGA. Therefore, we removed the sound information inside of the Main FPGA, and no sound information is passed to the Sub FPGAs. If a PC is used as an input device, there is no problem since one can change the sound device other than HDMI.

- Copy video stream to two HDMI outputs

Since the HDMI is a high-speed serial interface, the signal is first converted to parallel data and then copied to two outputs by serializing again.

2.3.2 Sub FPGA

Figure 8 shows the block diagram of the Sub FPGA. It has following functions.

- Input of HDMI signal
  
  HDMI video signal is deserialized and converted to a 16-bit color data per pixel.

- Write to DDR memory
  
  Color data is stored to DDR memory on the board.

- Read a specific region from DDR memory
  
  Two regions are read from DDR memory at the same time. One region corresponds to one video output. In the case of upper Sub FPGA, the order of reading pixels are opposite to the original orientation to achieve rotation of 180 degree. Note that enlarging roughly twice is needed to form a single image by four displays. Due to a bezel, enlarging exactly twice is not enough.

- Output HDMI signal
  
  Pixel data is serialized and is output from the HDMI connector.

2.4 Comparison with a single display

In this section, a mobile tiled display is compared with a single display in two points. Table
Table 1. Comparison of weight and power consumption

<table>
<thead>
<tr>
<th>System</th>
<th>Weight (kg)</th>
<th>Power Consumption (Watt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Our System</td>
<td>7.2</td>
<td>26</td>
</tr>
<tr>
<td>SHARP AQUOS LC-32H10</td>
<td>7.9</td>
<td>65</td>
</tr>
<tr>
<td>Toshiba Regza 32J7</td>
<td>8.0</td>
<td>81</td>
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<td>SONY Bravia KDL-32W600A</td>
<td>6.7</td>
<td>72</td>
</tr>
<tr>
<td>LG Smart TV 32LS3500</td>
<td>8.3</td>
<td>60</td>
</tr>
</tbody>
</table>

1 compares the weight and power consumption of displays. The size of the tiled display is roughly 32-inch since four 15.6-inch displays are used, and a bezel is added. Therefore we examined the weight and power consumption of 32-inch LCD panels. We chose four different LCD panels. Weight was from 6.7 to 8.3 kg, and power consumption was from 60 to 81 W. AQUOS LC-32H10 [8] from Sharp Corp. is adopted as a reference, since its weight and power consumption is in the middle range among other 32-inch displays.

Our system weighs 10.4 kg in total. A display part is 8.2 kg and a harness for shoulder mounting is 2.2 kg. Among the display part, 3.6 kg is for four LCD panels, 1 kg for batteries. Other heavy parts are wooden panels, cables, and FPGAs. Therefore, a display without batteries weight 7.2 kg. As for AQUOS, its weight is 7.9 kg only for LCD part.

The power consumption of our system is 26.25 W. The Main FPGA consumes 2.35 W, and each of the Sub FPGA consumes 3.15 W. Each LCD panel consumes 4.0 W and the smartphone consumes 1.6 W. On the other hand, AQUOS consumes 65 W.

From the comparison, the weight of our system is comparable to normal LCD panels, and the power consumption is lower than such panels.

3 FUTURE PLAN

Figure 9 shows the future plan of the tiled display, which looks like a vest with small displays attached. We plan to use 27 LCD panels of smartphones to form a wearable tiled display.

Figure 10 shows the block diagram of the wearable display. Similar to current one, a smartphone outputs an HDMI signal to an FPGA which has one input and three outputs with enlargement function. Then each HDMI signal is further divided into three HDMIIs by another FPGA. Finally, one HDMI signal is divided into three LVDS (Low Voltage Differential Signaling) signals with enlargement function. In total, 27 LCD panels are connected from one input.

Recent VR (Virtual Reality) technology often uses HMD (Head Mounted Display) and sensors, but wearable displays are not commercially available yet. A flexible display might be available in future, but currently a tiled display with small LCD panels is one of low-cost solutions to build a semi-flexible display.
4 CONCLUSION

We developed a mobile tiled display, which can be used as a wearable display like a sandwich man. Hardware implementation with FPGA enabled us to play a movie on the display just by connecting a smartphone. The power consumption of the system was lower than an LCD panel with equivalent size, while the weight was similar to a single one. We plan to develop a more lighter and flexible one by combining small LCD panels of smartphones. Such wearable displays would be used for many applications other than advertisement. For example, indicator of walking direction of people where many people gather, a new type of a battle game where players have to show the status of them to others via the display, and multilingual translator for communicating people with many different languages at the same time.

ACKNOWLEDGMENT

Author thanks Hikaru Yasueda for putting together the tiled display. This work was partially supported by JSPS KAKENHI Grant Number JP24500108.

REFERENCES


