The real-time dual band image fusion system with improved gray modulating fusion algorithm

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ABSTRACT
This paper analyzes the low-level-light image and ultraviolet image’s characteristics, and then the low-level-light and ultraviolet dual band false color preprocessing and fusion hardware system is put forward. To this system, real-time performance is an important factor. This system contains two parts. The first part is a FPGA+SDRAM architecture noise reducing system. The time domain average filter is applied to this part, because it meets the real-time requirement and can effectively decrease the low-light-level and ultraviolet image’s flicker noise. The second part is the fusion system. Its core is the most advanced video processor TMS320C6711. The processor’s EDMA can operate smartly to achieve the dual channel images’ capturing, calibrating and false color displaying without the core processor’s interference, while this trait is especially useful to the dual band image fusion system. In this part, for real-time performance consideration, the improved gray modulating fusion algorithm is used. The improvements aim at using the maximum potential of the core processor’s architecture. This paper gives the hardware data flow of the time domain average filter algorithm, the image registration algorithm and the improved gray modulating fusion algorithm in detail, and the system’s schematic is also included in this paper. This system achieves the low-level-light and ultraviolet image’s noise reducing, and solves the worldwide problem, the image registration. And most important it is a real-time hardware processing system and can be easy to integrate and equip.

Key words: real-time, dual band image fusion, gray modulating fusion, low-level-light, ultraviolet, the time domain image filter, image registration

1.INTRODUCTION
Recently, as more and more people think highly of the color night vision, the corresponding researches on dual band or multi-spectral image fusion make a rapid development. On the base of that, the techniques of low-level-light and ultraviolet image fusion make the corresponding development.

If we divide up the spectrum of the object’s low-level-light energy, some objects’ details are clear on one band, while others are clear on another band. Or, on a one band, the object’s details are clear but the outline is dim, and on another band, the outline is clear but the details are dim. It is possible to attain good details and outline of the low-level-light image, which just need to fuse the two bands of low-level-light image according to some good algorithm. All the above are the basic springboard of the fusion of low-level-light image and ultraviolet image. This paper analyzes the low-level-light image and ultraviolet image’s characteristics, designs a DSP+FPGA architecture low-level-light and ultraviolet dual band color fusion real-time system. Besides, this paper imports gray modulating algorithm to the system,
and improves gray modulating fusion algorithm to fit with the system’s characteristics, which aims at adapting the processing system’s architecture and meeting the real-time requirement.

2. ULTRAVIOLET IMAGE AND LOW-LEVEL-LIGHT IMAGE’S CHARACTERISTICS

Low-level-light image comes from the object and background reflecting the night nature radiation, so its most marked characteristics lie in that the image is added with obvious random flicker noise (electronic noise and ion noise). Moreover, lower illumination means more serious noise. At the same time, relative to the high illumination, the contrast and brightness of low-level-light image on the low illumination descend together, which representing in the histogram is that the gray region diminishes and the center moves to the low gray level.

Ultraviolet image comes from its own shortwave radiation of object and background, with low energy, low SNR and worse object compared to low-level-light image. But the most marked characteristic is that the ultraviolet image has high detecting and identifying probability in desert and sandstone zones, because the sandstone has very high reflectance on ultraviolet band.

![Low-level-light image and ultraviolet image and their histogram statistic](image)

Figure 1 indicates low-level-light image and ultraviolet image and their histogram. From the histogram, it can be seen that, because the low-level-light image and ultraviolet image show the object’s information of different wave bands, they have different scenery’s details.

Low-level-light image and ultraviolet image each have different characteristic information, the image fusion aims at reserving as more information of the two images as possible.

3. ARCHITECTURE OF THE FUSION SYSTEM
The implementation of the system is to place ultraviolet CCD and low-level-light CCD side by side, and then acquire two images which have different observing angles. As figure 2, the right one is ultraviolet CCD, and the other one is low-level-light CCD.

![Image of ultraviolet and low-level-light CCD](image_url)

Fig 2. Ultraviolet and low-level-light CCD place side by side simulating double-eyes of people

The system’s processor adopts DSP+FPGA architecture, and its flow chart indicates in figure 3.

![Architecture of system’s processor](image_url)

Fig 3. Architecture of system’s processor

The outputs of both ultraviolet and low-level-light CCD are analog video signals, which will be digitized by A/D converter. Before fusion, the time domain average filter and the image registration should be applied first. The time
domain average filter and the image registration are both implemented in FPGA, while the image fusion is achieved in DSP. The basic idea of the time domain average filter is to get average value from several consecutive frames.

In the system, A/D is PHILIPS’s SAA7111, FPGA is ALTERA’s EP1S10F780, DSP is TI’s TMS320C6711, SDRAM is HYNIUX’s HY57V561620, D/A is TI’s THS8134.

The size of output image from A/D is 768*576, but for real-time performance consideration, we only take the middle 512*512 portion. Although 512*512 image can’t display full screen in 800*600 resolution, it will not affect the displaying effect.

At last, three channel images, which are the ultraviolet average filtered image, the low-level-light average filtered image and the ultraviolet and low-level-light fusion image export to CRT’s three-color channels separately. Finally, color display comes ture.

![Fig 4. system color fusion project](image)

### 4. PREPROCESSING MODULE DESIGN

#### 4.1 The time domain average filtering algorithm

The image enhancer output image has very low SNR, which will affect the quality of the image and the object identifying probability seriously. So in order to enhance the useful information and restrain the useless information, before the dual band fusion processing, the noise reducing processing must be done to enhance the image. The algorithm of time domain processing is convenient for hardware implementation, so this paper adopts the time domain average filter. The time domain average filter can be described as, at the time of \( T_n \), image \( F_n \) \(( T_n \) frame), image \( F_{n-1} \) \(( T_{n-1} \) frame), …… and image \( F_{n-m} \) \(( T_{n-m} \) frame) are accumulated together, and then the result image \( F_{n\_out} \) is got by equation (1).

\[
F_{n\_out} = \left( F_n - F_{n-1} + \cdots + F_{n-m} \right) / m
\]  

(1)

For convenience to hardware processing, the algorithm should be improved.

\[
F_{n\_sum} = F_{n\_sum\_out} - F_{n-m} + F_n
\]  

(2)

\[
F_{n\_out} = F_{n\_sum} / m
\]  

(3)

#### 4.2 The image registration algorithm

The image registration is a worldwide problem, and to this system, real-time registration is impossible to implement. From analyzing the characteristics of ultraviolet and low-level-light images, it can be found that they have the same size...
image, and have little aberrance. It only needs horizontal and vertical move. So this system takes low-level-light image as benchmark, and reads out ultraviolet image from memory. The head address of the ultraviolet image controlled by human input, and this can achieve the ultraviolet image’s horizontal and vertical move.

4.3 System implementation of the time domain average filtering and image registration

The interior logic of FPGA implement time domain average filter and image registration, and there are seven PIPEs (PIPE L1, L2, L3, L4, L5, L6, L7) taking charge low-level-light image processing, and other seven PIPEs (PIPE U1, U2, U3, U4, U5, U6, U7) taking charge ultraviolet image processing. Because of the same processing algorithm and symmetrical architecture, it only needs to introduce the low-level-light processing part, and the ultraviolet processing part is the same.

Fig 5. The time domain average filter and image registration’s implement in FPGA
PIPE is a dual buffer logic, which is constructed by interior RAM and logic of FPGA. The two buffers take charge reading and writing alternately. When one port writes date, the other port reads date. When both reading and writing are completed, the two buffers exchange. The PIPE’s one buffer could just store a row of image, that is to say the entire processing takes a row as basic processing unit.

Ten PIPEs compete for SDRAM domination via SDRAM CONTROLLER, and the winner writes date to SDRAM or reads date from SDRAM. After the date transmission completes, the winning PIPE will release domination, so that other PIPEs can go on competing for the domination.

PIPE L1 captures the current frame of low-level-light image, and stores them into SDRAM. PIPE L2, L3, L4, L5 take charge the time domain average filtering. Choose m=4. PIPE L2 reads \( F_{\text{sum}}^{n} \) and PIPE L3 reads \( F_{n-m}^{n} \), so uses the two above and current frame \( F_{n}^{n} \) to calculate the \( F_{\text{sum}}^{n} \) and \( F_{\text{out}}^{n} \). After that, PIPE L4 is used to store \( F_{\text{sum}}^{n} \) into SDRAM, PIPE L5 is used to store \( F_{\text{out}}^{n} \) into SDRAM. PIPE L6 reads the date being processed by the time domain average filter and transmits to DSP to fuse with ultraviolet image. Differently, PIPE L7 reads the date of time domain average filtering for displaying. The processing course between ultraviolet and low-level-light are same. The difference is that PIPE U6 contains image registration in addition, and implements the ultraviolet image’s horizontal and vertical move controlled by human input.

5. FUSION MODULE DESIGN

5.1 Gray modulating

Gray modulating fusion is to put the normalizing image multiplied by another image, then quantize the result and display.

Suppose the low-level-light image is \( LL \), and the ultraviolet image is \( UV \). Do normalizing processing with the low-level-light image, then acquire the image \( LL^{*} \),

\[
LL^{*}(i, j) = \frac{[LL(i, j) - \min LL]}{[\max LL - \min LL]}
\]  \hspace{1cm} (4)

Then do modulating, image \( LL^{*}(i, j) \) multiplied by image \( UV \)

\[
F(i, j) = LL^{*}(i, j) \times UV(i, j)
\]  \hspace{1cm} (5)

\( F(i, j) \) is the fusion image. In order to match the fusion image \( F(i, j) \) with the dynamic range of displaying equipment, it needs to be quantized. This dynamic range of gray level is from 0 to 255. The quantization method as follows:

\[
F^{*}(i, j) = 255 \times \frac{F(i, j) - \min[F(i, j)]}{[\max F(i, j) - \min F(i, j)]}
\]  \hspace{1cm} (6)

The gained \( F^{*}(i, j) \) is the final gray modulating fusion image. For accommodating with the DSP’s high speed operation and meeting the real-time requirement, the fusion formula is improved. The fusion formula could be gained by the combination of formula (4), (5), (6):

\[
F^{*} = a \times [LL(i, j) - b] \times [UV(i, j) - c]
\]

\[
a = \frac{255}{(\max LL - \min LL) \times (\max LS - \min LS)}
\]
\[ b = \min LL \]
\[ c = \min LS \]

(7)

In this way, FPGA’s PIPE L6 and PIPE U6 could be used for the statistic of maxLL, minLL, maxLS, minLS, that is to say the value of a, b, c, could be calculated before DSP processing a frame of image. This will greatly save the DSP’s capacity of processing data.

In the fusion processing, PIPE is also applied. But this PIPE not only contains the PIPE which constructed by FPGA, but also PIP module which taking along with DSP’s EDMA and DSP’s BIOS, and dual-buffer which constructed by the interior RAM of DSP.

Fig 6. The fusion algorithm’s implement in FPGA and DSP

PIPE L and PIPE U read out the low-level-light image and ultraviolet image separately, which have been processed by time domain average filter and image fusion. For the assistant of EDMA, DSP write the data of PIPE L and PIPE U to PIPE D1 and PIPE D2. PIPE D1 and D2 correspond to \( LL(i, j) \) and \( UV(i, j) \) of formula (7). DSP core put the two data into formula (7), then add the statistics result such as maxLL, minLL, maxLS, minLS which are in front of a frame data and are calculated by FPGA. At last the fusion image can be got. Here all PIPEs take a row as basic unit. The
fusion image should be stored into SDRAM via the DSP’s PIPE D3 and FPGA’s PIPE F1. PIPE F2 read out the fusion image.

In this way, PIPE F2, PIPE L7 and PIPE U7 connect to D/A’s red, green and blue channel separately, and the color image is formed.

6. CONCLUSION

This paper gives the hardware data flow of the time domain average filter algorithm, the image registration algorithm and the improved gray modulating fusion algorithm in detail, and the system’s schematic is also included in this paper. This system achieves the low-level-light and ultra-violet image’s noise reducing, and solves the worldwide problem, the image registration. Though this system is in debugging, it will soon be integrated and equipped.

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