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Monitor for Anti-Aircraft Guidance and Observation Systems

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Abstract. The fire control system operator's monitor unit displays the video feed from online video cameras and fire control system-generated on-screen data overlays. The design specified in this paper and developed by the authors is a hardware implementation of GUI on-screen data overlays from various data sources to minimise the fire control system's CPU load. The monitor unit can acquire video feeds from two cameras, with one daylight (full colour) VIS camera and one IR (monochromatic) camera and the video output generated by the fire control system computer and overlay or mix the two video sources on-screen. Each of the video camera feeds can be processed in real time with gamma and dynamic brightness range correction. The daylight VIS camera feed processing supports video pixel change detection to substitute for a motion detection system. The fire control system monitor can also analyse the video feeds and overlay the hazy areas of the VIS camera feed output with the corresponding areas of IR camera feed output.

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The fire control system monitor supports IR camera feed PIP (Picture-in-Picture) display overlaid on the VIS camera display, mixing of both camera feeds, and panoramic view output from both video feeds. On-screen text and a moving targeting crosshair can also be displayed. The fire control system monitor communicates with its master control system via a serial bus. The monitor can also work autonomously (not connected to a master control system); commands and status output functions are implemented with a bezel control keyboard with individually backlit keys. The functionalities were developed with relatively simple hardware and software solutions.
Keywords: vision systems, military monitor, hardware image processing, video fusion, motion detection

1. INTRODUCTION

A primary feature of video imaging systems applied in anti-aircraft defense platforms is the simultaneous display of video feed from the online sensors and the data generated by the fire control system. Considering the processing power and overall performance of the computer systems available today, a software implementation of the following functionalities is possible: from image acquisition through target tracking and ballistical (firing) solutions to controlling weapon motion actuators and firing mechanisms, simultaneously generating a full video output for the fire control system operation, all with a single processing unit.

Considering the potential necessity of operation in emergency or derated modes and the technical requirements of equipment operated by the Polish Armed Forces, it also seems prudent to consider a monitor unit design for fire control systems which would accept video feeds from one or more cameras and from the fire control system computer, and generate the final video output for the operator.

This paper discusses a monitor unit which embodies the foregoing functionalities. Despite the relative simplicity of the applied hardware and software solutions, the monitor unit can process video feeds to modify them and overlay and mix the processed video outputs.

2. BASIC DESIGN SPECIFICATIONS

The minimum accepted functionalities of the monitor unit are:

- acquisition of two live video camera feeds in PAL format;
- acquisition of a fire control system computer video output in XGA standard;
- 7:1 LVDS based LCD panel operation;
- DVI output for a peripheral video monitor.

The video output parameters conform to the XGA standard with a resolution of 1024 × 768 pixels and a 60 Hz refresh rate.

The minimum video camera feed processing operations include video streams synchronization, deinterlacing, resolution scaling and contrast (gamma) correction. The following video output types were defined:

- selected (online) camera feed output;
- computer-generated output;
- video output composition of selected (online) video camera feed pixels or the fire control system computer output pixels, where either alternative selection criteria is the computer output pixel brightness level.

Given the technological limitations, no BGA-packaged hardware components were applied.

3. HARDWARE

The analogue PAL video feed inputs are processed into a digital format by two identical video feed decoders and written to a two-port static RAM (random access memory) module. The RAM output reading and processing is synced with the data output from a downstream signal decoder which acquires the XGA signal.

The video signal composed of three image/video inputs is output to an LCD of the monitor unit and, via a DVI encoder, a peripheral display unit (if connected).

Fig. 1. Monitor unit during climatic tests

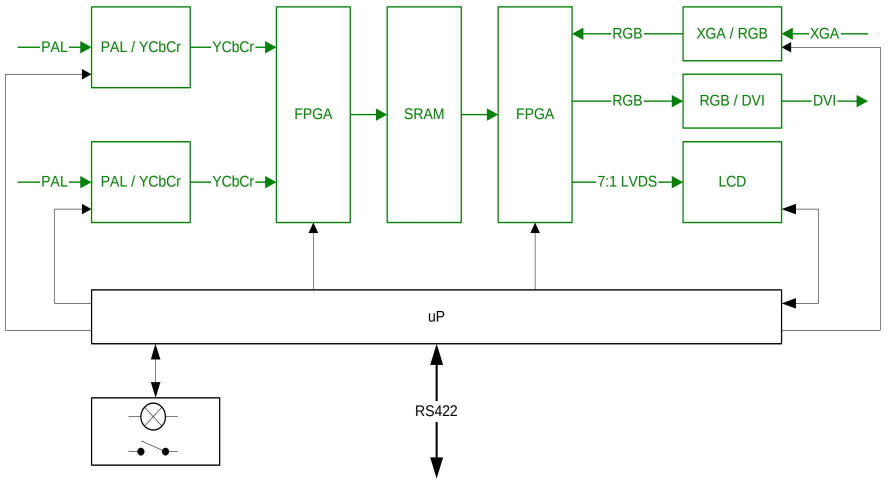

Fig. 2. Monitor unit block diagram

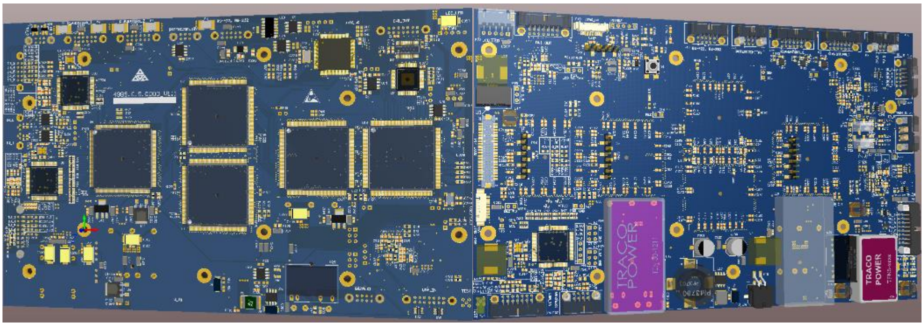

Fig. 3. Monitor unit motherboard

A control processor handles the data communication with the master control system (if connected), monitors the bezel keyboard inputs, the LCD panel backlight status and operating temperature, and enables a switchover to the autonomous operating mode of the monitor unit.

In the primary operating mode, the operator inputs the commands for the master control system with the bezel keyboard. The feedback with the system status indication is based on the bezel key backlights (each of which is independent backlight in any colour) and on-screen text display.

4. VIDEO IMAGE PROCESSING

4.1. PAL video feed acquisition

The PAL video feed acquisition encoders generate output signals in YCbCr 4:4:4 standard. For the VIS camera feed, the RAM module saves the full colour and brightness data for the successive frame pixels. For the IR camera, the RAM module saves the brightness data only. The two-port RAM module access mode provides a sequential deinterleaved video reading.

Irrespective of the video contents being saved, each successive video feed field from the VIS camera is divided into rectangular areas and processed with the following procedures:

- During even video field:
  - a monochromatic image is generated at a reduced resolution;

$$F_{x,y}^{(l)} = \frac{1}{n}\sum Y^{(l)}(i,j)$$

  - a time-averaged image is computed

$$H_{x,y}^{(l)} = \frac{rH_{x,y}^{(l-1)} + F_{x,y}^{(l)}}{r = 1}$$

- During odd video field:
  - thresholding of the image change values;

$$A_{x,y}^{(l)} = \left|\begin{matrix} \left|H_{x,y}^{(l)} - F_{x,y}^{(l)}\right| \leq L_{min} \rightarrow 1 \\ \left|H_{x,y}^{(l)} - F_{x,y}^{(l)}\right| > L_{min} \rightarrow 1 \end{matrix}\right.$$

  - computing of the quantity of image changes above each threshold;

$$S^{(l)} = \sum_{x,y} A_{x,y}^{(l)}$$

  - relationship check

$$Q^{(l)} = \left|\begin{matrix} S^{(l)} > S_{max} \longrightarrow 1 \\ S^{(l)} \leq S_{max} \longrightarrow 0 \end{matrix}\right.$$

Filter ratio, r, thresholding level, $L_{\min}$, and maximum number of indicated image changes, $S_{\max}$, are set arbitrarily either by the master control system or the monitor unit operator. The processing results $A^{(l)}$ and $Q^{(l)}$ are written in the RAM module.

4.2. Camera video feed processing

The RAM module contains YCbCr video feed images at resolution 720 × 576 pixels. The first processing operations modify the pixel luminance:

- gamma correction

$$Y_G = Y_I^{\gamma}$$

also done for $\gamma = 1$ to simplify the algorithm;

- dynamic brightness range correction (expansion)

$$Y_F = F(Y_G, Y_{min}, Y_{max})$$

where values of $Y_{\min}$, $Y_{\max}$, which map the minimum and maximum brightness, are determined and set according to the analysis of the last image acquired.

The subsequent operations are applied to the VIS camera video feed pixels

- image change detection indication by changing the colours of the pixels in the area of detectable changes

$$[Y_S, Cb_S, Cr_S]_{x,y} = \left| \begin{array}{l} QA_{x,y} = 1 \ \rightarrow [Y_S, b, r]_{x,y} \\ QA_{x,y} = 0 \ \rightarrow \ [Y_S, Cb_I, Cr_I]_{x,y} \end{array} \right.$$

- conversion to RGB space

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = K \begin{bmatrix} Y_S \\ Cb_S \\ Cr_S \end{bmatrix}$$

Next, the resolution of both video feeds (from the VIS and IR cameras) is rescaled to XGA, and to the video output for the external monitor unit, 1024 × 768 pixels. Lanczos-2 algorithm was applied for this. Both video feeds in this resolution:

- have on-screen text or a targeting crosshair overlaid.

The last operation, which is applied to the VIS camera video feed only, is:

- pixel conversion to HSV space

$$\begin{bmatrix} H \\ S \\ V \end{bmatrix} = Z(R, G, B)$$

Downstream processing depends on the active operating mode of the monitor unit. By applying designations mapped as follows: TV for the VIS camera feed, IR for the IR camera feed, and PAL for the monitor unit video output display, the following is executed:

- "Monitor": the whole video feed output of the selected (online) is displayed;

$$PAL_{x,y} = \left| \begin{array}{lll} tv = 1 & \rightarrow & TV_{x,y} \\ tv = 0 & \rightarrow & IR_{x,y} \end{array} \right. ;$$

- "PIP": the VIS camera feed is displayed without an operator-defined rectangle in which the IR camera feed is displayed;

$$PAL_{x,y} = \left| \begin{array}{lll} (x,y) \notin XY & \rightarrow & TV_{x,y} \\ (x,y) \in XY & \rightarrow & IR_{x,y} \end{array} \right. ;$$

- "Fusion": the displayed pixel source is determined by the IR camera feed pixel brightness (Y_{IR}) and the brightness (Y_{TV}) and colour (H_{TV}) of the VIS camera feed pixel;

$$\left(Y_{IR_{x,y}} > I_{min}\right) \cap \left(Y_{TV_{x,y}} < T_{max}\right) \cap \left(H_{min} < H_{TV_{x,y}} < H_{max}\right) \rightarrow f_{x,y} = 1$$

$$PAL_{x,y} = \left| \begin{array}{lll} f_{x,y} = 0 & \rightarrow & TV_{x,y} \\ f_{x,y} = 1 & \rightarrow & IR_{x,y} \end{array} \right. ;$$

- "Panoramic View": the monitor output is a composition of both camera feed images set side by side.

4.3. Fusing the camera feeds with the computer-generated output

The last processing step before the monitor video output is displayed is to merge the processing results of the foregoing algorithms with the video image generated by the fire control system. By applying designations mapped as follows: XGA for the external system video feed and LCD the final video output on the monitor unit display, the following is executed:

- camera video feed

$$LCD = PAL$$

- system-generated video

$$LCD = XGA$$

- camera video feed OR system-generated video

$$LCD = \left| \begin{array}{l} Luminancja(XGA) < L_p \rightarrow PAL \\ Luminancja(XGA) \geq L_p \rightarrow XGA \end{array} \right.$$

with L_p being a defined threshold value;

- camera video feed OR system-generated video

$$LCD = r\,PAL + (1 - r)XGA$$

with r being the video mixing ratio

- camera video feed OR camera video feed OR system-generated video

$$LCD = \begin{cases} Luminancja(XGA) < L_p \rightarrow PAL \\ Luminancja(XGA) \geq L_p \rightarrow r\,PAL + (1 - r)XGA \end{cases}$$

5. EXAMPLES OF FUNCTIONALITIES PROVIDED WITH THE APPLIED PROCESSING METHODS

5.1. Video fusion

A high-performance vision system is mission-critical to situational awareness and reconnaissance, especially in visually-degraded ambient conditions. Situational awareness can be enhanced in poor or unfavourable ambient lighting with VIS cameras and IR cameras. However, operation of two video displays may result in information overload and data transmission uplink overload. The monitor unit discussed here solves this problem by generating video images composed of both camera feed scenes. The VIS camera video feed is overlaid with the IR camera video feed only in the areas the monitor unit qualifies as too hazy.

Fig. 4. Video fusion

The displayed pixel source is determined by the thermal imaging camera feed pixel brightness (Y_{IR}) and the brightness (Y_{TV}) and colour (H_{TV}) of the VIS camera feed pixel;

$$\left(Y_{IR\,x,y} > I_{min}\right) \cap \left(Y_{TV\,x,y} < T_{max}\right) \cap \left(H_{min} < H_{TV\,x,y} < H_{max}\right) \rightarrow f_{x,y} = 1$$

$$PAL_{x,y} = \begin{vmatrix} f_{x,y} = 0 & \rightarrow & TV_{x,y} \\ f_{x,y} = 1 & \rightarrow & IR_{x,y} \end{vmatrix};$$

5.2. Target zoom

Another important feature which improves situational awareness is the capability of observation of wide-field operating areas and detailed identification of tracked objects. The monitor unit can output two video feeds on a single display.

Fig. 5. Target zoom

“PIP”: the VIS camera feed is displayed without an operator-defined rectangle in which the IR camera feed is displayed;

$$PAL_{x,y} = \begin{vmatrix} (x,y) \notin XY & \rightarrow & TV_{x,y} \\ (x,y) \in XY & \rightarrow & IR_{x,y} \end{vmatrix};$$

5.3. Panoramic view

An optimal vision system should be capable of real-time 360° FOV observation. Due to its hardware limitations, the monitor unit can fuse the video feeds from two sensors to enhance the field of view. DDR standard compliant RAM modules are required to fuse video feeds from more than two sensors.

Fig. 6. Panoramic view

5.4. Image change detection

A major functionality which can enhance situational awareness and security, especially for observation positions, is the motion detection feature based on image change detection.

The monitor unit highlights the areas of the video feed which change with a contrasting colour or displays an "ALERT" frame, monitor also outputs the coordinates of the object detected by image change to the fire control system. If the entire video feed field (the whole sensor) moves, the monitor unit suspends image change detection.

The motion detection feature, combined with a video tracker solution can automatically detect and track signatures of objects appearing in the FOV, which can prove to be useful especially in anti-aircraft/air defense applications.

Fig. 7. Motion detection

Image change detection indication by changing the colours of the pixels in the area of detectable changes

$$[Y_S, Cb_S, Cr_S]_{x,y} = \left| \begin{array}{l} QA_{x,y} = 1 \ \rightarrow [Y_S, b, r]_{x,y} \\ QA_{x,y} = 0 \ \rightarrow \ [Y_S, Cb_I, Cr_I]_{x,y} \end{array} \right.$$

5.5. Gamma correction and dynamic brightness histogram correction

Fig. 8. Gamma correction and dynamic brightness histogram correction

The features designed for correction of video parameters in relation to the ambient parameters markedly enhances observation capabilities. The monitor unit features an implementation of gamma correction and dynamic brightness histogram correction in specific video feed image areas. Gamma correction

$$Y_G = Y_I^{\gamma}$$

also done for $\gamma = 1$ *to simplify the algorithm*;

Dynamic brightness range correction (expansion)

$$Y_F = F(Y_G, Y_{min}, Y_{max})$$

where values of $Y_{\min}$, $Y_{\max}$, *which map the minimum and maximum brightness, are determined and set according to the analysis of the last image acquired.*

5.6. Targeting crosshair and ballistic converter

The monitor unit can overlay a targeting crosshair and enables its repositioning within the display area according to the data outputs from the targeting system. The integrated non-volatile memory module can store the targeting crosshair coordinates according to the preset target distance.

Fig. 9. Targeting crosshair and ballistic converter

5.7. On-screen text display

Aside from the sensor video feed overlays on the computer-generated video output, the monitor unit can overlay on-screen text.

The text information can either originate from the master control system or from the monitor unit’s memory module to provide descriptions of bezel key functions, for example.

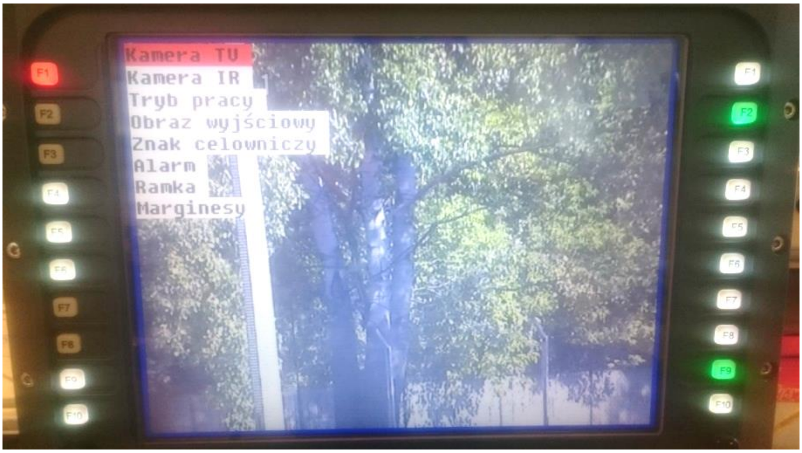

Fig. 10. On-screen text display

5.8. Other functional features

- The monitor unit meets the environmental requirements NO-06-A103 for N.12 devices and EMC requirements of NO-06-A200:2012; KCE-02 KRE-02.
- The LCD backlight is 1600 cd/m2 to permit operation in strong direct sunlight.
- The night-vision mode of the bezel keyboard displays data readable only with night vision equipment.

6. CONCLUSION

Hardware video processing methods are fast in execution and require little CPU computing power.

The hardware solutions applied in the monitor unit allowed implementing additional and useful functionalities. The monitor unit can be used as a backup (emergency) targeting system.

The functionalities of the monitor unit permit configuration of a system in which the master fire control computer is replaced with a suitable microcontroller device, what yields the following benefits:

- Improved system reliability.
- Reduced system costs.
- No export licensing required.
- Improved system security.
- Flexible system customization.

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REFERENCES

[1] Malina Witold, Sergey Ablameyko, Waldemar Pawlak. 2002. *Podstawy cyfrowego przetwarzania obrazów*. Warszawa: Akademicka Oficyna Wydawnicza EXIT.

Monitor dla przeciwlotniczych systemów naprowadzania i systemów obserwacyjnych

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Streszczenie. Monitor operatora systemu kierowania ogniem wyświetla obraz pochodzący z aktualnie używanych kamer oraz nałożone na ten obraz informacje generowane przez system. Opisana w artykule konstrukcja, opracowana przez autorów niniejszego tekstu, realizuje sprzętowo funkcję nakładania informacji z różnych źródeł, minimalizując obciążenie jednostki centralnej systemu. Monitor umożliwia akwizycję sygnału z dwóch kamer, w założeniu dziennej oraz termalnej (obraz monochromatyczny), akwizycję obrazu generowanego przez komputer systemu kierowania ogniem oraz nakładanie lub mieszanie tych obrazów. Ponadto dla każdej z kamer realizowana jest korekta gamma i korekta zakresu jasności obrazu. Dla obrazu z kamery dziennej wykonywana jest procedura detekcji zmian obrazu, mogąca stanowić namiastkę wykrywania ruchu, oraz analiza umożliwiająca zastąpienie obrazem z kamery termalnej w obszarach uznanych za zamglone (fuzja). Możliwe jest także wyświetlanie obrazu z kamery termalnej w wybranym obszarze monitora („obraz w obrazie") na tle obrazu z kamery dziennej, ew. mieszanie tych obrazów oraz tworzenie panoramy z obrazów z obu kamer. Dodatkowo realizowane jest wyświetlanie informacji tekstowych oraz ruchomego znaku celowniczego. Sterowanie pracą monitora przez system nadrzędny odbywa się za pośrednictwem magistrali szeregowej. Możliwa jest także praca autonomiczna, dzięki klawiaturze wokółekranowej wyposażonej w indywidualnie podświetlane przyciski, zapewniającej zarówno sterowanie, jak i sygnalizację stanu. Powyższe efekty uzyskano przy użyciu stosunkowo prostych rozwiązań sprzętowych i programowych.
Słowa kluczowe: systemy wizyjne, monitor militarny, sprzętowe przetwarzanie obrazu, fuzja wideo, wykrywanie ruchu