LED Projector of Pulse Backlight for Machine Vision System

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Abstract. The paper presents technical description of pulse LED backlight. This system is implemented in machine vision systems designed for high-speed processes control. Pulse projectors managed on the basis of starting time and duration of the pulse. The system provides control of electrical parameters of projectors, such as input voltage and current of the LED array, which are measured during backlight pulse operate time. This information gives an indirect measurement of the LED arrays’ state. The design of the system and implementation example are given.

1. Introduction
At present, machine vision systems are widely used for operational control of technological processes. An important part of such systems is the artificial illumination of the scene. Solution to this problem is given a lot of attention, according to the literary sources [1-7]. Correctly designed backlight provides more contrast image of the controlled objects. This leads to a significant reduction in computational operations in the construction of object contours and, subsequently, effective segmentation of the image [8].

Modern technologies make possible development of the high-performance backlight projectors based on LED. Such projectors are used by WipWare in machine vision systems Momentum and Solo, which are designed to control the grain-size distribution of crushed material moving on a conveyor belt [9]. Similar projectors are used in the VisioRock system manufactured by Metso Cisa [10]. These systems used LED projectors in a continuous mode. However, when tracking the high-speed processes, such as the motion of ore on the conveyor, a video camera operates in electronic shutter mode. In this mode, the video frame forming time (~ 0.1 ÷ 1 msec) is significantly shorter than the time between the formations of consecutive video frames: at a shooting frequency of 60 frames per second, the interval between frames is 16.6 msec. Thus, there is no need for continuous operation of projectors in this mode. Synchronizing the video frame forming time with the pulse starting time can significantly increase the light flux. For example, according to the technical documentation for LEDs LEMWA33X70JX [11], it is possible to form a light flux almost 3 times greater in the pulsed mode than in the continuous one. Moreover, there are high chances that the operation of LEDs in pulse mode will increase their operation time. This article is devoted to the description of a LED projector operating in a pulsed mode.

2. LED projector of pulse backlight
LED projector is a dual-board design in a sealed case (IP65) with a glass-covered lid. The boards are stacked on each other and are interconnected by two single-row PLS (PBS) connectors. On the top board the LED array of 10 LEDs LEMWA33X70JX, with monitoring circuits of the current array, is
unsoldered. LEDs are equipped with focusing lenses LA-11, which increases the light flux by concentrating it on the object. On the lower board the project control circuit is mounted.

LED projector ready fitted with mounting bracket provides possibility to change the angle of the projector case in two directions. Through the hermetic cable entry, the projector is connected to a camera and backlight controller (VSLC), which provides power and control.

2.1. Functional circuit of the LED projector

The functional circuit of LED projector (figure 1) consists of the following functional units: input voltage sensor, controlled voltage regulator, LED array, backlight pulse key, current array control circuit, control microcontroller, bus driver and power supply regulator.

The LED array of the projector should be switched on for a certain time interval synchronously with the exposure moment of the video camera, which is provided by the microcontroller by the pulse on the BUSD bus. BUSD bus receives the control commands for the backlight pulse parameters and the service commands from the controller. In response, the information about the input voltage and the current of the array, measured during the backlight pulse operate time, is transmitted from the projectors. This information indirectly characterizes the state of the LED arrays.

![Figure 1. The functional circuit of LED projector.](image)

The control of the luminous intensity of the LEDs is not carried out, since the maximum possible luminous flux is required from the projectors. A current sensor is used to monitor the channel current.

2.2. Forming of the backlight pulse

The LED projectors bus is used both for information exchange and for synchronization of backlight processes, i.e., transmission of sync pulses.

Figure 2 illustrates the relationship of cyclic processes on BUSD bus. At the beginning of the cycle, the VSLC controller generates a 4 ms pause, keeping the bus at zero level. Then SYNC_PULSE sync pulse of the video camera exposure with a duration of 20 μs is formed at the output of SYNC. After that the FLASH_DELAY pause for the ending of the transient processes of the video camera is started. At the end of the Flash Delay pause, BUSD bus is set to a high level for EXPOS_TIME exposure time, and a low level after its completion, thereby creating a trigger pulse with the duration of EXPOS_TIME.

Projector controllers on the rising edge of the trigger pulse include the keys of their arrays, thus triggering a work flash (the key is turned off after the FLASHWIDTH pulse expires).
Figure 2. Signal envelops, which illustrate the interconnection of processes on the BUSD bus.

By the decay of the pulse on BUSD bus, the projector controllers turn on the array again to form a 20 μs ADDFLASH measurement pulse. Only the current is measured during the pulse. The input voltage and voltage of the LED array are measured when the array is turned off.

Then the logic-1 level pause before the exchange is established and maintained for 700 μs. In case if the VSLC controller does not start transmitting a packet for projectors during this time (time instant "Start transfer"), then after another 50 μs the receiving of the response packet can start.

In any case, the timeout starts for 11.5 ms, which is reliably more than transmit-receive time for the data packet. At the end of the timeout any exchange is terminated, and on the bus a zero level is generated for the time remaining until the end of the cycle (16.6 ~ 4.4 ms).

Figure 3. Oscillograms of the formation of backlight pulses. The upper (yellow) indicator shows the backlight pulses (left pulse is working, 7 μs, right one is measuring, 20 μs); the lower (blue) indicator shows FLASH pulse from the video camera on the left oscillogram and a trigger pulse in the BUSD channel on the right one.

The oscillograms in figure 3 should be interpreted as follows. Synchronization of the oscillograph is carried out by an external channel from the front of the video camera trigger pulse (a pulse of 20 μs, which image is absent in the oscillograms). At the end of this pulse, a delay is triggered, which takes into account all the transient processes in the video camera, and after that the exposure is started. This time point on the oscillogram corresponds to the Flash Window pulse droop. If the beginning of the working pulse is coincided with the specified moment or located to the right of it on the time axis, then the target object will be highlighted with maximum efficiency.

The working backlight pulse is formed by all projectors on the rising edge of the trigger pulse on the bus, while the measuring pulse – by its the droop (right oscillogram at figure 3), which is eliminated an ambient light. The backlight pulses are formed with a delay about 8 μs from the front and the decay of the trigger pulse on BUSD bus.
The width of the trigger pulse on the bus is 84 μs, which corresponds to the set exposure time of the video camera - 80 μs, plus the program response time to the timer interruption. On the left oscillogram (figure 3) you can see that the camera "removes" the Flash Window signal also after 80 μs.

2.3. BUSD bus. Data exchange with LED projectors

The data exchange between the controller and the LED projectors includes the transfer of commands from the controller, either broadcast or an individual address, and the transmission of data from each projector about its current state. It is intended to use up to 16 LED projectors in the backlight system. While exchange, the following commands can be used:

- survey "LIVE" (individual address);
- request for version "VERSION" (individual address);
- write registers "REGS_WR" (broadcast address);

2.3.1. Link level. At the link layer, the exchange protocol works as follows. During the exchange the controller can generate either address packets for each of the 16 projectors, which should receive answers in the next cycle, or broadcast packets, which require no response.

Figure 4 shows that while exchange each transmission cycle follows by the reception cycle over the BUSD bus, and if a broadcast packet is transmitted, then the transmission from the projectors is absent in the next cycle.

![Figure 4. Exchange envelopes over the BUSD bus.](image)

2.3.2. Physical level. Exchange over the bus at the physical level is similar to the physics of the USART protocol (RS-232). An 8-bit packet has start and stop bits, so the total number of bits per byte is 10, and the total number of bits per packet is 10·16=160. Due to this circumstance, the bit interval is reduced to 70 μs.

The transmission time of a 16-bytes packet with a duration of a bit interval of 70 μs, will be $70 \cdot 10 \cdot 16 = 11.2$ ms. For the minimum repetition period of the sync pulses equal to 16.6 ms (the shooting speed is 60 fps) and the packet preamble time is greater / equal to 10 bit intervals – 0.7 ms, it is remains about $16.6 - 0.2 - 11.5 = 4.9$ ms for pauses. The preamble before the exchange is selected equal to 0.7 ms, the pause before the sync pulse is 4.2 ms.

2.4. Assigning addresses to LED projectors

When manufacturing LED projectors, each device is assigned an individual number by means of jumpers. This number is indicated both on the board and on the case of the projector. During an installation the LED projectors can be placed in any order.

3. Local console

The VSLC controller provides the local service management using any laptop equipped with a COM port. For this purpose, the controller includes an optically isolated COM port driver.

Using a pre-installed terminal emulator program (for example, PCommLite by Moxa Inc), you can control the switching on of LED projectors, change the contents of the control registers, view the contents of the current and voltage measurement registers of both the controller and projectors.

To work with the local console, it is necessary to remove the upper cover of the switching box body and connect the RS232 cable to the COM port connector (DB9), run the console program on the computer and turn on the controller power. The information about controller registers will be displayed in the window of the console program. Using the command line, it is possible to perform certain actions with the controller.
The program supports 2 screens: the main screen and the help one, which are shown in figure 5. The help screen displays the syntax of the commands. To enter the help screen, input the command `help`, to return to the main screen - `work`.

![Screen shots](image)

**Figure 5.** Local console program: a) main screen, b) help screen.

The main screen displays the following information (top to bottom, left to right):

- **Screen name.** Name of the program. Software version (Ver)
- **General settings of the backlight pulse parameters:** current (CURNT), duration (EXPOZ), delay (DELAY).
- **Projector parameters in a table of 6 columns and 16 lines:** number (SPOT), array current (MX_Currn), array voltage (MX_Voltg), input voltage (IN_Voltg), projector status (Stat - ON/OFF) and software version (Versn).
- **Video camera status (CAM).**
- **The input voltage of the controller (INP_VOLTAGE).**
- **Message line of the program (MESSAGE).**
- **Command input string (input ->).**

The following commands are available to the user for input:

- **General reset command - `reset`.**
- **Commands for switching on (`onNN/`) and off (`ofNN/`) of the projector with the NN number.** If the number is not specified or equal to 0, then the command is valid for all projectors.
- **Pulse width setting command (`pw/DDD`), where `DDD` is a number from 10 to 200 μs.**
- **Pulse delay set command (`pd/DD`), where `DD` is a number from 1 to 50 μs.**
- **Current setting command (`mcNN/DDD`) with current value `DDD` of the projector with number `NN`.** If the number is omitted or equal to 0, then all projectors are executed.
- **Voltage setting command (`mvNN/DDD`) with voltage value `DDD` of projector with number `NN`.** If the number is omitted or equal to 0, then all projectors are executed.
- **Projector software version request (`ver/NN`).** Here the indication of the number is required.

The values of the measured parameters of the projectors: the current and voltage of the array, as well as the input voltage of the projector are displayed sequentially in the table.

4. **Conclusion**

The article describes the control system of LED backlight. The backlight consists of projectors and controlled by a microcontroller. The projector receives the parameters of the backlight pulse (beginning and duration of the pulse) and the service commands. In response, information about the input voltage and matrix current is transmitted from the projector to the controller. Such a system
provides generation of light pulses ranging in duration from a few microseconds to 1 ms. Feedback from LED projectors gives a control of their performance. In this system, there is no need to control the temperature of the LEDs. With an increase in the luminous flux (~ 2-3 times) and, consequently, the current of the LEDs, the time between adjacent pulses is large enough to cool the LEDs by natural means.

The described system was implemented in software and hardware complex, designed to assess the particle size distribution of pieces of crushed ore, moving on a conveyor belt. The complex is installed in the large-scale crushing workshop at EVRAZ-KGOK. LED backlighting ensures the formation of high-contrast images of pieces of crushed ore in conditions of high dust content of the workshop. For all the time of operation, the system demonstrates high reliability and excellent performance [12, 13].

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