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Design of the System for Automatic Grain Size Analysis at Ore Mining and Processing Enterprises

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Abstract. The paper is devoted to the vision system for determining the grain-size distribution of finely crushed particles (~ 0.1mm in size) of bulk material moving on a conveyor belt. A block diagram of the system and data exchange protocol are presented. The commands for high-speed LED pulse backlight control are provided. The functional diagram and principle of the LED matrix control are described. The results of a full-scale testing of the system at the mining and processing plant are presented. As a result of the full-scale testing of the system at the mining and processing plant, the absolute error varies from 1.2% for the class "+ 4.0mm" to 5.2% for the class "-0.1mm". The absolute error for the target "+ 1.0mm" is 2.5%.

1. Introduction

Mineral ore is passed through several processing stages to obtain the desired mineral. At each of this stage, the crushing of a source material is performed. Beginning with blasting in the open-cast, the ore mass is comminuted until it becomes possible to concentrate it in one way or another in order to obtain the desired mineral.

For operational control of the mineral ore processing, devices with high reliability, performance, advanced functionality and extended accuracy are needed. The most all these requirements are met by devices based on the systems of machine vision [1-5]. An advantage of such systems is the non-contact way of the target objects measurement.

In machine vision systems, a radar [6], laser [7-9], or video camera are used to obtain the image of a bulk layer of a crushed or granulated material. Radar or laser allows you to form a 3D image, while a video camera gives a 2D image in common. However, in the analysis of the ore mass, the operative control of its geological composition is of great importance. This task can be solved with a video camera only by isolating and analyzing the color and texture features of ore particles [3,10].

By now, several systems for the operational grain-size analysis of crushed or granulated material have been developed and implemented. A brief description and comparative analysis of such systems as SPLIT, WIPFRAG, FRAGSCAN, CIAS, IPACS, TUCIPS is given in [5]. These systems use cameras with a minimum exposure time of 1/10,000 sec for the purpose of determining the grain-size composition of ore particles with dimensions of ~ 5 ÷ 7 mm. For the case of fine-crushed particles with a size of ~ 0.1 mm while the conveyor speed is about 1.0 m/sec and margin of sample error is 1%, the minimum exposure time of the video camera should be 100 times smaller. To fulfill such conditions, it is necessary either to use expensive high-speed video cameras or to control the intensifier pulse both by the duration and by the formation moment. This article is devoted to the design of the machine vision system that provides for the fulfillment of technical requirements for the obtaining of appropriate images of fine-crushed particles.

2. Structural configuration of the system

Structural scheme of the system is given in figure 1. The system consists of the following components:

- Adapter unit, which is connected to PC via COM port. Controller exchanges signals with adapter unit via symmetrical bus BUSU (twisted pair wire) using modified protocol m-bus.
- Switch unit CSU protect the power line from an overvoltage and the control line from a lighting discharge.
- Camera is powered by a constant voltage +12VDC from the controller card and exchanged control signals with controller using its own galvanically isolated interface.
- LED projectors are powered by voltage 50VDC from power supply unit. Signal exchange with controller is implemented using single-line asymmetrical bus BUSD.
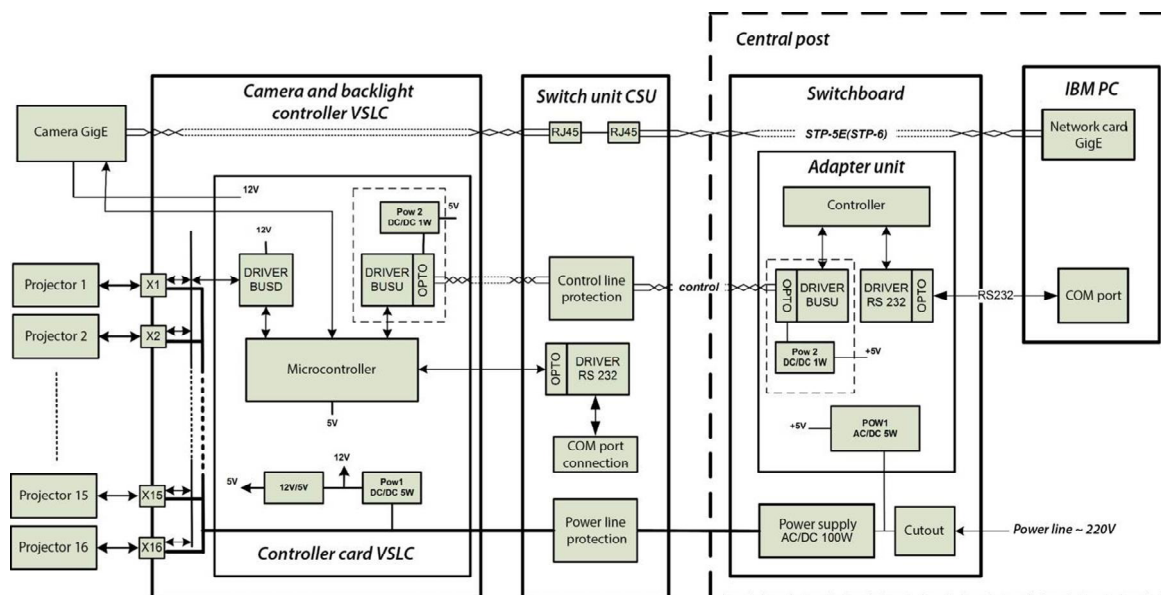

Figure 1. Structural configuration of the system.

3. Data exchange

As follows from the structural scheme in figure 1, the connection between the operator's workplace and the camera and backlight controller, as well as connected projectors, is made through a composite heterogeneous channel (figure 2).

Bottom-upwards: the common bus BUS_DOWN (BUS_D) that connects the LED projectors to the controller, bus BUS_UP (BUS_U) from the controller to the adapter unit, and the RS232 bus from the adapter unit to the PC.

At the transport level, all communications are carried out through a pass-through protocol such as modbus-ASCII.

The system devices exchange information packets with the source and destination addresses and contain commands and (optionally) data. In response to the received packet, any device in the system sends an acknowledgment (ticket) - ASK, which is a pulse of a certain duration for the BUS bus, and a short packet of two special symbols '$' and LF (0Ah) for the USART bus.

The system modules exchange data in the order shown in figure 2. The initiator of the exchange is the PC (control console program), all devices are only responding.
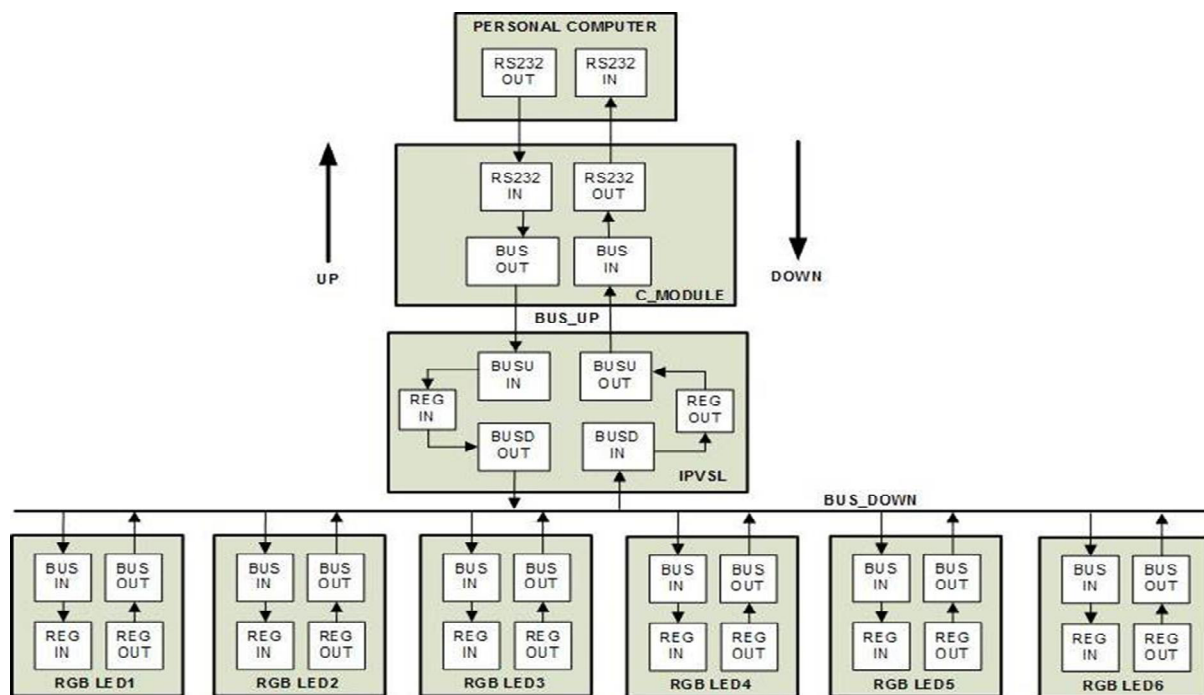
Figure 2. Data exchange in the system.

In the downward direction from the console, polling commands to the system units and control commands are received. In the upward direction, there are packets with the status data of the system units and responses to the console commands.

The camera and backlight controller accepts commands addressed to him and to projectors. Projectors' control commands are transmitted by the controller either to the specific projector or to a broadcast address, which allows them to be applied to all projectors at once. Upon polling command, the controller sends to the console address a packet with data on the state of the projectors and its own. The VSLC controller collects statistics on the state of the projectors by periodically generating polling commands via BUSD bus.

Table 1. HEX packet for the upper-layer protocol.

Byte num.	Data field num.	Data field name	System units				
			Operator console	Adapter unit	Receiver-corrector	Video sensor	Projector
0	1	Packet heading terminator	'$' (36h)				
1	2	Destination address	20h	40h	60h	80h	A0h – AFh, BFh
2	3	Source address	20h	40h	60h	80h	A0h – AFh
3	4	Command and data block code	0bCCCCKKKK, where C..C – command code, KKKK– data block code				
4 - 13	5	Data field	HEX - 10 bytes				
14	6	Hash total	XOR of bytes from 0 till 13				
15	7	Packet ending terminator	LF (0Ah)				

The structure of the information packet consisting of 7 fields is given in table 1.

The following fields are highlighted in the packet of 16 bytes: Destination address (1 byte), Source address (1 byte), Command and data block code (1 byte), Data field (10 bytes) Hash total. The package is framed by terminators: the heading and ending of the packet.

1.   The device type (name) field (3 high-ordered bytes):

- DEV = 1 – Operator console,
- DEV = 2 – Adapter unit,

- DEV = 3 – Receiver –corrector (not used),
- DEV = 4 – Video sensor (camera and backlight controller),
- DEV = 5 – Projector.

2. Number field (5 low-ordered bytes) NUMB=0..31 – which is used for projectors only. Full addresses of projectors: A0h, A1h,... AFh. BFh – broadcasting address.

System management includes setting the operating mode of the projectors, the parameters of the intensifier pulse, the current of the LED array (through setting the array voltage).

The operating modes are controlled through the CONTRL_REG register (data block code -1). The matrix current is controlled via two-byte registers MX_CSET_REG, MX_VOLT_REG (data block code -2). The intensifier pulse parameters are controlled via 2 single-byte registers for pulse duration and delay WIDTH_PLS, DELAY_PLS (data block code -3). If the data block code is 0, then all control registers are transmitted. The status registers store information about the current values of the voltages and currents of the units, their statuses, as well as the version number, etc.

The command is transmitted in the third byte of the packet (the highest tetrad), coded by a nibble, so their maximum number is 15.

1. Device polling command - LIVE. Code, 3h. Multifunctional command:
   - It is periodically sent to the address of the controller, which, in turn, sends this command sequentially to the addresses of the projectors for the purpose of monitoring the console operability. The packet with the measured parameters should be sent back to the source address.
   - It is generated by the controller in a cycle of projectors polling.

2. Register bank writing command - REGS_WR, Code - 4h. This command is modified, the heading of the block and the number of bytes are excluded from the command, instead of them the code of the register group (the lowest tetrad of field 4) is used. The data for writing to the controllers' registers are transferred starting from the zero byte of the data field, no more than 10 bytes can be written per one command. The response packet is a copy initial one with inverted source and destination addresses.

3. Register bank reading command - REGS_RD, Code - 5h. The command is always sent by the master to the slave of any level. This command is modified, the heading of the block and the number of bytes are excluded from the command, instead of them the code of the register group (the lowest tetrad of field 4) is used. In the response packet, the slave device transmits the values of all control registers starting with a zero byte (you can read no more than 10 bytes per command).

4. Program version request command - VERSION, Code - 6h. The command is sent by the master to the slave device of any level. In the response packet, the version number of the software in the Ver.Rel format is transmitted in the data field, where Ver is the version number (the first byte of the data field), Rel is the release number (the second byte of the data field). (The version number is also sent in the response packet of the LIVE command).

5. Packet transfer error command - TXD_ERR, Code - 7h. The command is intended for the console and can be transferred by any device of the system.

6. Initialization mode switching command - SYS_INIT Code - 8h. The content of the zero byte of the data block defines the function of the SYS_INIT command: Byte 0 = RESET_INIT (0xC) is a system reset.

4. Design of the video sensor

The device integrates a video camera in its own protective case, a VSLC controller and 16 projectors.

The video sensor design (figure 3) is a tapered frame formed by two horizontal panels (top cover and mounting plate) and six inclined ribs. The lower part of the frame, for additional rigidity, is connected by spacer tubes. Removable protective cover plates (not shown in the figure) are mounted on the fins to prevent splashes and dust from getting inside the sensor.

The internal volume of the sensor is divided vertically into two parts: the upper, protected by the IP44 class, in which the video camera and the controller are located, and the lower - the open one, in which the projectors of the backlight are arranged in two circles of 8 items each.
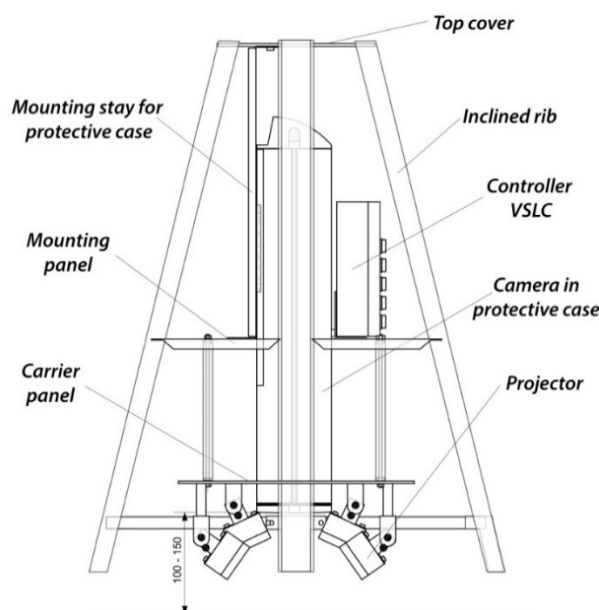

Figure 3. Video sensor.

The position of the carrier panel in vertical is selected by the criterion of maximum approach to the illuminated video object, in which the mechanical safety of the lower lamps is still performed. The supporting panel of the projectors 4 is fixed with vertically threaded ties that run inside the aluminum tubes. The upper ends of the couplers are fixed with nuts to the frame mounting plate.

Projectors are electrically connected to the controller by cables (not shown in the figure 3), which are passed into special holes made in the mounting panel. The camera is also connected to the controller with a power and control cable, through the connector on the casing.

Table 2. The results of the industrial tests.

№	Data source		Grain-size class output, %					
			+5.0	+4.0	+1.0	+0.5	+0.1	-0.1
1	Laboratory		0.8	1.0	46.5	15.4	10.5	25.8
	System's software		0	0	46	17	16	21
		Absolute error	0.8	1	0.5	1.6	5.5	4.8
2	Laboratory		1.1	1.7	46.3	15.6	14.3	21.0
	System's software		0	2	42.0	18	16	22.0
		Absolute error	1.1	0.3	4.3	2.4	1.7	1
3	Laboratory		1.5	1.6	45.6	14.9	12.4	24.0
	System's software		0	2	45	17	15	21
		Absolute error	1.5	0.4	0.6	2.1	2.6	3
4	Laboratory		20.5	4.1	37.7	14.1	18.1	5.5
	System's software		18	2	33	15	14	18
		Absolute error	2.5	2.1	4.7	0.9	4.1	12.5
5	Laboratory		17.7	4.3	37.5	14.5	18.4	7.6
	System's software		19	2	40	14	12	13
		Absolute error	1.3	2.3	2.5	0.5	6.4	5.4
Average error			**1,4**	**1,2**	**2,5**	**1,5**	**4,1**	**5,3**

5. Conclusion

The described system is developed and passed industrial tests at the enterprise of JSC "EVRAZ-KGOK". According to the program of industrial tests, the laboratory of product quality management carried out the sampling of fine-crushed particles for the purpose of grain-size distribution analysis for the classes: "-0.1mm", "+ 0.1mm", "+ 0.5mm", "+ 1.0mm", "4.0mm" and "+ 5.0mm". At the same time, the same parameters were recorded according to the output of the system software. The results of experiments on the evaluation of the grain-size distribution of fine-crushed particles are presented in Table 2.

The obtained results show that the developed system accurately determines the grain-size distribution of the fine-crushed material. The increasing of the error for the classes "-0.1mm" and "+ 0.1mm" is due to the fact that the controlled material was moist. In this state, small particles either stick together with each other and form larger pieces, or stick to large pieces, which reducing their quantity. However, according to experts of "EVRAZ-KGOK", in the production of sinter the class "+1.0 mm" is of the most interest. The average absolute error in determining this class was only 2.5%.

Also, the hardware failures were not detected during the industrial tests of the system. Thus, the proposed design of the hardware part of the system showed its high efficiency and reliability in the mining and processing industry.

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