A software and hardware system for synchronous control of the optical system for visual control of dynamic objects

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Abstract. This work deals with the development of the software for the system of synchronous control of the optical system of visual control over dynamic objects and the creation of algorithms for resolving conflicts of simultaneous illumination by several light sources. The software for the microcontroller for the system hardware is created as part of the work. An application for remote configuration of the device is developed. Algorithms for time-separation of signals for switching on lighting are implemented.

1. Introduction
Additional lighting is used in any experiment to avoid unnecessary complications. Observation is realized either directly with the experimenter’s eyes, or with the help of cameras. The development of visual control systems for dynamic objects in industrial conditions is an urgent and popular task for improving the quality of products and reducing production costs [1–3]. Visual inspection of products allows performing both high-precision measurements of geometric parameters [4–5] and visual inspection of surface defects of manufactured products [6]. Due to their physical characteristics, cameras require more light than the human eye to distinguish important details of the object being studied. To increase the lighting power without changing the light source itself, you can use pulsed illumination. The supply of current higher than the operating value for a short time provides greater brightness. The light source does not have time to overheat and fail. In addition, the pulse illumination prevents from interfere with other measurements taking place on the same setup. Such systems are often used on conveyor belts to control manufactured products. The limited space on the production line forces multiple cameras to be used for monitoring on the one place. When implementing a system for the visual control of dynamically moving objects, it is necessary to solve a number of problems related to synchronization of the time of switching on the illuminator and opening the shutter of the photodetector. There are ready-made solutions for simultaneous operation with several channels, designed for synchronizing the photodetector and the illuminator [7]. But these devices cannot be flexibly configured during operation. In addition, the architecture of existing solutions does not provide for control over the overlap of different signals over time. There is also no priority of the output signals, which does not guarantee the operation of important nodes in specialized tasks. The purpose of this work is to develop software for controlling the hardware of the system for visual control of dynamic objects, which will provide stable synchronous operation of several illuminators and cameras with events prioritization.
2. Method description

The functional diagram of the developed visualization system is shown in Figure 1. The design of the visual control system provides for a single production line, along which the measured objects move linearly. The object (5), passing through the one beam IR photobARRIER (2), generates a signal from the sensor, which is processed by the microcontroller (1). Next, the microcontroller must turn on the illuminator sequentially at the right time points (3) and synchronize the lighting with the beginning of the camera frame (4). Cameras with the possibility of external control are used. The shutter speed and exposure time are set programmatically, and the frame start time is set hardware-wise by applying a sync signal. The visual control system can have several cameras and illuminators. In this case, an additional task is imposed on the microcontroller to control these devices in turn.

![Figure 1. Functional scheme for the developed synchronization system: 1 – microcontroller, 2 – photobARRIER, 3 – illuminator, 4 – camera, 5 – measured object](image)

Since different observations and measurements have to occur independently of each other, it is necessary to solve the problem of separating the overlapping illumination cases when collisions occur between different events. When working with a separate illuminator and a camera, it is necessary to synchronize the lighting of the illuminator so that the object is illuminated during the entire period when the camera aperture is open (Fig. 2).

![Figure 2. Synchronization of illuminator and camera.](image)

The experiment is conducted with a dynamic object, so its velocity may change during operation, which means that the time between the passage of the photo barrier and the entry of the object into the measurement zone may change. It may also be necessary to change the illumination time of the illuminator or limit the maximum time of the switched-on lighting at the hardware level to avoid overheating of the light source. The microcontroller must be able to work simultaneously with several cameras and illuminators, respectively.
3. Experimental results

3.1. Choosing a hardware platform
To solve this problem, the Iskra Neo programmable platform based on the 8-bit ATmega32u4 microcontroller is used. This board is compatible with many extensions that allow flexibly configuring the system for various tasks. The built-in microcontroller operates at a frequency of 16 MHz and has 32 KB of flash memory for storing firmware, which is sufficient to write all the necessary software. At that, 1KB of built-in non-volatile memory is enough to store more than 100 integer parameters. The number of general-purpose I/O ports is 20, which allows managing multiple external devices simultaneously.

3.2. Software Development
The software for the selected microcontroller is developed. The software controls four cameras and three illuminators simultaneously, turning them on at different times depending on the incoming signal. Two operating modes are implemented. In the first mode of operation, all the lights are turned on simultaneously and the camera shutters are opened after a fixed time. In the second mode, the lights and photo applications are turned on at different times, configured by the operator. Switching on is carried out by sending a signal to one of the contacts of the microcontroller. The microcontroller sends a signal to the illuminator power driver because it cannot provide enough voltage and current for powerful lighting. To control the camera shutter, a signal of 5 volts from the pin of the microcontroller is sufficient.

The developed microcontroller software provides flexibility in the number of controlled devices and allows adding more controlled cameras and lights without major changes.

All delay times between the arrival of the input signal and the inclusion of a particular output signal are parameterized. Since the objects’ velocity may vary, the parameters include the distance between the reader that generates the input signal and the measurement location, as well as the line speed for calculating the power-on delay:

\[ T = \frac{L}{V} + T_i + \text{delay}_{i1}, \]  

where \( L \) is the length in mm, \( V \) is the line speed, \( T_i \) is the hardware power-on delay, and \( \text{delay}_{i1} \) is the time offset of a particular device.

These parameters are stored in non-volatile memory and restored automatically after restarting the device. When the device is configured remotely, the parameters are updated in non-volatile memory. Moreover, the data is updated only if one of the values changes. This provides a longer memory work, since this type of memory has a limited number of rewrite cycles. It can move the parameter recording area to use a different memory area if the previously used one has exhausted its resource. All parameters come over the Ethernet network using a specialized communication protocol written on top of TCP/IP. This protocol includes the header with the parcel code, the checksum, the total package size, the number of parameters, and the parameters listed. A server is implemented on board, which in response to a request for updating parameters sends a confirmation with information about the updated parameters.

To remember the flash time of a particular illuminator, a priority sortable queue is implemented in the memory of the microcontroller. Its elements are a data structure that stores the time of the object's passage in the measured zone and the type of illuminator that needs to blink. After receiving the input signal from the photobARRIER, a new value is written to the queue. A binary search for a suitable place to add a new item is implemented for the queue to be always sorted on-time. This avoids viewing the entire queue when searching for the next illuminator's turn-on time, but allows controlling only the first element. This approach significantly speeds up the operating time of the device. Since the duration of each flash may be unique, the time when the illuminator is turned off is also recorded in a separate queue with a note about the type of recording and which illuminator or camera needs to be turned off. Parameterization of the flash time, the delay between the arrival of the input signal from
the photo barrier and the inclusion of the illuminator occur at the stage of turning on the device or
during operation.

When working with objects of different lengths, it is necessary to record the moment when the
object leaves the measurement area. Since the length of the object is not always known in advance, the
microcontroller must handle not only the change in the input signal on the front up, but also on the
front down. In this case, two shooting events may overlap at the same time. The first occurs as a result
of the change in the input signal on the front up, the second-on the front down (Fig. 3). It is necessary
to separate in time these two events, so that the illuminator does not interfere with another video
camera. For this purpose, an algorithm for distributing close signals with the possibility of
prioritization has been developed. Before being added to the queue, the existing nearest record is
checked. If the switch-on time difference is less than the pre-set delta, then either the existing record
or the new one that is currently being added is corrected, depending on the priority of the signals.

![Figure 3. Waveform of the intersection of two illuminator switching signals from one input signal. The upper graph is the input signal, the lower graph is the output signal to the illuminator and camera. The arrows show the time when the illuminator should blink. When the delay increases or the subsequent object lengthens, two signals will overlap, and the illuminator will turn on once, instead of two separate ones.](image)

For remote configuration of the device using a computer over a wired network, an EthernetShield
expansion card is used with a connection speed of up to 100 Mbit/s. This allows you to configure the
device parameters from a long distance without stopping the main operation process.

To debug the hardware or check for errors in case of signal loss, the debugging mode with the
output of information about the current state of the system has been added. Communication is carried
out over virtual COM port via micro-USB interface.

### 3.3. An application for a personal computer

An application for a personal computer designed for remote configuration of the device, which allows
you to transfer new operation parameters to the microcontroller, has been developed. The application
opens a configuration file, from which the new operation parameters are recognized. These parameters
are formed into a single package in a certain format (Fig. 4) and sent to the microcontroller over the
Ethernet network. With this application, you can send parameters to several devices at once, by setting
all the IP addresses of the necessary devices in the network.
Conclusions
A software and hardware system for synchronous control of an optical system for visual control of dynamic objects has been developed. Microcontroller software has been created that allows you to synchronize multiple light sources and cameras. The device is configured over the network. The turn-on time is stored in a sorted queue that allows you to turn on different lights and cameras sequentially.

An algorithm is implemented to separate overlapping highlighting cases when collisions occur between different events.

Developed applications for a personal computer for remote configuration of the device.

The developed software and hardware system has successfully passed field tests for observing more than 10 dynamic objects per second with observation using three cameras and 4 illuminators on three different installations with different configurations.

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