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Development of intelligent control system for X-ray streak camera in diagnostic instrument manipulator

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ABSTRACT

An intelligent control system for an X ray streak camera in a diagnostic instrument manipulator (DIM) is proposed and implemented, which can control time delay, electric focusing, image gain adjustment, switch of sweep voltage, acquiring environment parameters etc. The system consists of 16 A/D converters and 16 D/A converters, a 32-channel general purpose input/output (GPIO) and two sensors. An isolated DC/DC converter with multi-outputs and a single mode fiber were adopted to reduce the interference generated by the common ground among the A/D, D/A and I/O. The software was designed using graphical programming language and can remotely access the corresponding instrument from a website. The entire intelligent control system can acquire the desirable data at a speed of 30 Mb/s and store it for later analysis. The intelligent system was implemented on a streak camera in a DIM and it shows a temporal resolution of 11.25 ps, spatial distortion of less than 10% and dynamic range of 279:1. The intelligent control system has been successfully used in a streak camera to verify the synchronization of multi-channel laser on the Inertial Confinement Fusion Facility.

1. Introduction

The streak camera is an ultra-high-speed detector that captures light emission phenomena occurring over extremely short time periods. The streak camera can measure intensity variations with superb temporal resolution, and it can also be used for simultaneous measurement of the spatial (or spectral) distribution. Therefore it is widely used as an ultrafast diagnostic tool in the physics of Inertial Confinement Fusion (ICF) [1,2]. Currently, the high-performance streak camera is developed in Japan [3], Russia [4], Germany, France [5,6] and the United Kingdom [7]. In addition to the product features of high reliability and long life, modular design is also a current development trend for the streak camera. In an earlier paper [11], Liu developed a modularized hardware system for the streak camera; however, a potential malfunction may have been induced from the interference of high anode voltages and the ground of A/D modules.

In the study reported in this paper, to avoid being exposed to the hazardous electromagnetic radiation, an intelligent control system was proposed and implemented, which could remotely control the time delay, electric focusing, image gain adjustment, switch of sweep voltage and CCD recording system. In addition, the scanning state, real-time voltages were also detected. An intelligent control system was designed using a modular design method. An isolated DC/DC converter with multi-output and a data sampling module with differential inputs were adopted to reduce the common mode noise induced by the interference of high anode voltages and the ground of ADC module. Moreover, a single mode fiber was adopted to further reduce the interference. The software was designed using graphics language (Labview). A smooth algorithm was adopted in the software to reduce the measurement error. The triggering jitter, temporal resolution and scanning nonlinearity were tested with this intelligent control system in a diagnostic instrument manipulator (DIM).

2. Intelligent system design

Fig. 1 shows a schematic diagram of streak camera. As shown in this figure, the streak camera consists of an image intensifier, high voltage and low voltage power supply modules, slit optical system, CCD recording system, intelligent control system, scan control

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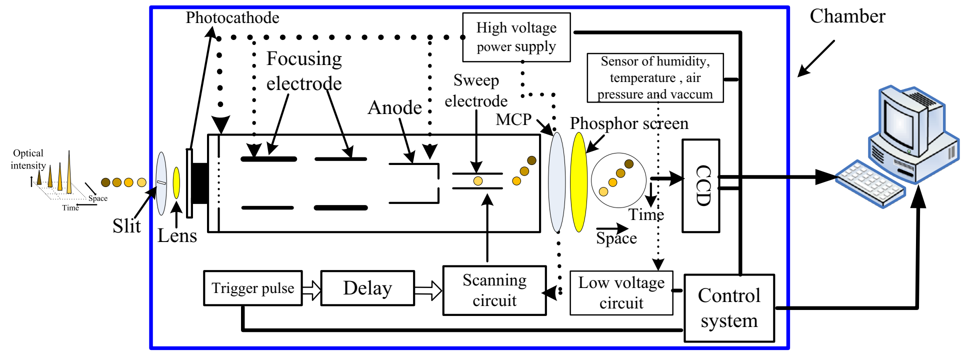

Fig. 1. Schematic diagram of streak camera.

system control scanning system and a streak tube. The streak tube was comprised of a photoelectric cathode, electric quadrupole and a group of electrodes including a time focusing electrode and scanning template electrode, grid electrode, anode, focusing electrode and second focusing anode. A ramp signal is applied to the scanning control modules to achieve ultra-fast scanning. The streak camera is widely used in an ultra-fast diagnostic system, which is normally comprised of an X-ray streak camera tube, industrial control system, high voltage power supply and a scanning control system. In real applications, all of the modules are accommodated into an air chamber which has a limited volume.

With different light intensity, temporal and spatial offset, the light pulses to be measured passes through the slit and is focused on the photocathode of the streak tube by the input optics. Then, the light pulses are converted into corresponding electron ones, which are proportional to the intensity of the incident light. The electron pulses are accelerated by a high electrical field and focused on the screen by an electro-optical focusing system, when they pass through a pair of sweep electrodes supplied by a linearly rising high voltage, then bombarded on different position of phosphor screen along the scanning direction of the deflector. In Fig. 1, the scanning direction is from top to bottom. At this point, the streak camera realized the transformation of signal from temporal domain to spatial ones. To intensify the image, a micro-channel plate (MCP) is equipped in front of the phosphor screen, As the electrons pass the MCP, they are multiplied several thousand times and are then bombarded against the phosphor screen. On the phosphor screen, the phosphor image corresponding to the optical pulse which was the earliest to arrive is placed in the uppermost position, with the other images being arranged in sequential order from top to bottom; the brightness of the various phosphor images is proportional to the intensity of the respective incident optical pulses. The position in the horizontal direction of the phosphor image corresponds to the horizontal location of the incident light. In this way, the streak camera can be used to convert changes in the temporal and spatial light intensity of the light being measured into an image showing the brightness distribution on the phosphor screen. We can thus find the optical intensity from the phosphor image, and the time and incident light position from the location of the phosphor image.

As can be seen in Fig. 1, the intelligent control module should effectively control the time delay, electric focusing, image gain adjustment, CCD recording system, acquisition of the environmental parameters and the status of scan stage switch, etc. The other main parameters and indexes are listed in Table 1

To avoid the micro-targets, widely used in physical experiments, from being affected by environmental parameters, factors such as temperature, humidity, air pressure, water leakage and vacuum also need to be collected.

Table 1
Parameters in streak camera.

Items	Detected parameters	Controlled parameters	Input/output (TTL)
Static voltage control	1	1	1
Static voltage detect		1	1
Shutter control and monitoring			2
Trigger mode			1
Reset function			1
Width adjustment			1
Gain adjustment	1		4
Gain detect			1
2.65 V control			1
Cathode voltage control	1		1
Cathode voltage detect			1
Screen voltage control			1
Screen voltage detect			1
Strong self-protect	1		1
Scan enable			1
Scanning speed switch			6
Prebias power supply	6	6	1
Scanning power supply	6	6	2
State protection			2

2.1. Hardware system design

As shown in Table 1, to detect the working state, working voltage in real time and obtain control of the sweep voltage, power supply and external equipment, the entire system required a 16-channel A/D, 16-channel D/A converters and a 32-channel bidirectional I/O port at the TTL level. The TTL I/O signal is used to set the electromagnetic valve, cooling switch, velocity of circulating water flow etc. All of the parameters were assigned to several **CAN** modules shown in Fig. 2.

In Fig. 2 the designed hardware module of intelligent control system is displayed. As shown, the module consisted of a signal detecting module, a control block, a group of I/Os, a main control unit and sensors. The signal detecting module was comprised of 4 A/D converters each having 4 channels with differential input. The control block included 4 D/A converters. The detected analog signal was converted to a digital signal by the A/D converters and sent to the main control unit. The main control unit received the data and compared it with the predetermined values, then sent the values to the D/A converters. The D/A converters adjusted the output voltage accordingly. The sensors were used to detect the environmental parameters such as air pressure, temperature, humidity etc. The main control unit communicates with the other module through **CAN** bus. The entire system communicated with the computer through a single optical fiber and a network module that converted the optical signal to an electrical signal in which the **TCP/IP** was inserted.