EMBEDDED CONTROLLER FOR INDUSTRIAL CT TRIGGER MODULE

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Abstract

The industrial CT is used to generate a 3D image of the inside of an object; it consists of an accelerator x-ray source, detector array, readout electronics and control system. A trigger module collects the position information from three decoders installed all the 3 moving axis and generates trigger signal to the x-ray source and readout electronics. The trigger module is remotely accessed by the SCS (system control station) via a fast Ethernet connection. The trigger module utilizes an embedded controller board which consists of a PowerPC controller running the Linux operation system, and a FPGA connected to the PowerPC local bus as a customized peripheral to carry out the trigger logic. With different interface mezzanines and online firmware upgrade, the trigger module has great flexibility to work with different decoders readout electronics.

INTRODUCTION

Originally developed as a medical diagnostic tool, the Computed Tomography (CT) can provide detailed internal information of human body. This technology has also been applied to non-destructive inspect objects that have the indispensable requirement for safety and reliability like high-speed railway train wheels or the air plane turbine engineers. Without the constraints of patient movements or dose restrictions that exist in the medical CT, the industrial CT can achieve better resolution by applying much stronger x-ray source and a much longer exposal time [1].

The industrial CT consists of an x-rays tube, a rotary table, the detector array, the readout electronics, the trigger module and the data analyse and image reconstruction computer.

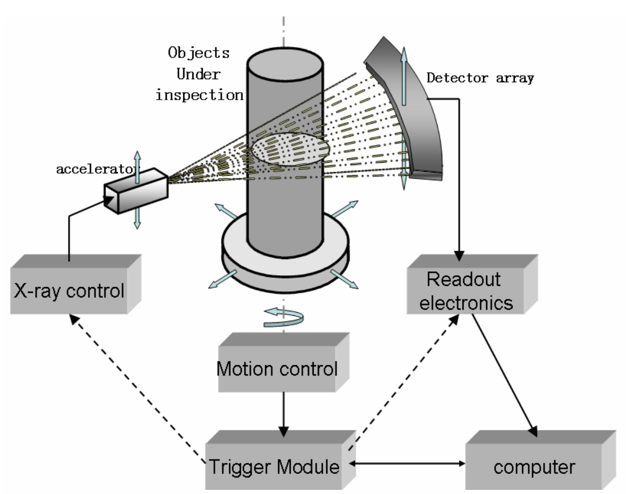

Figure 1: typical schematic block diagram of industrial CT.

A typical schematic block diagram of industrial CT is given in figure 1.

The object to be inspected is located on the rotary table between the x-ray tube and the detector; the X-ray source and the detector are relatively stationary and can move together in the vertical direction along the object; the rotary table can move in two directions and rotate. By setting the relative motion between object and the x-ray/detectors, the industrial CT can be configured to work in direct radiography (DR) mode, second generation CT mode or third-generation CT mode. The x-ray source is working in pulse mode to reduce radiation dose and prolong the life, the readout electronics are also work in gated integration mode to suppress the detector dark noise.

TRIGGER MODULE STRUCTURE

As seen from Figure 1, the trigger module is one of the key components in the industrial CT; it connects with all the other control blocks and manipulates the working flow of the equipment. The functional block structure of the trigger module is shown in figure 2; a picture of the module is given in figure 3.

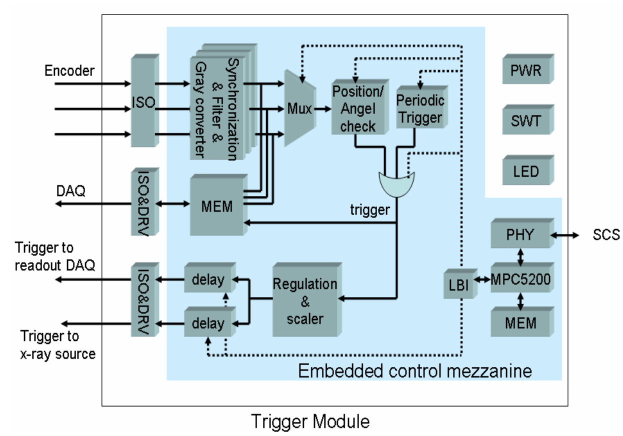

Figure 2: Functional block of trigger module.

Its main function blocks are provided by the embedded control mezzanine which will be described later. A description of all the other elements is given below:

Encoder input

In each axle of the drive motor, there is an absolute rotary encoder installed. They have 16 resolution bits and 8 turns bits to cover the whole scan range. The position and angle the object under inspection can be achieved from the output of these encoders, which are normally in gray code that has only one bit difference between any two consecutive values.

The output of those encoders are converted into the local electrical domain by isolation transistors, a 3 out of 3 low-pass filter removes the noise glitch signals that couple into the cable, then the original Gray code are converted into binary code for following process.

Two types of encoders are foreseen to be used: the parallel type has a separate signal for each bit; the serial type multiplexes all bits to be sent via a single signal using the SSI protocol. A multi-channel low speed photo-coupler mezzanine is used for parallel type while a single channel high speed magnetic coupler mezzanine is used for serial type. Both mezzanines have the same connector definition thus can be easily replaced.

Trigger output

Depending on the working mode, when the specific encoder outputs indicates that the object has reached a pre-defined position, the trigger module sends a trigger to activate the x-ray source, also sends a trigger to the readout electronics to start integration and conversion after a certain delay caused by the x-ray source latency and detector response time.

The internal trigger logic is working in pipeline mode that can deliver consecutive trigger pulses. Due the limitation of motion system and the minimum trigger width requirement from both x-ray source and readout electronics, the internal trigger pulses are first modulated and pre-scaled before send out. The time delay can be adjusted independently in the step of 10ns for both the x-ray source and readout electronics.

External input

In some product types there are special requirements which need external inputs to the trigger module. For example, in order to inspect the gap of air plane turbine blades, the turbine must be in operation during the inspection. In this case, the motion system is steady but the object itself is rotating, thus the trigger module can be synchronized by the signal from turbine gear control system.

The external input can also used for the safety interlock to avoid unexpected radiation.

DAQ interface

The image reconstruction algorithm needs to know the geometrical position and angel for each acquired tomography slice. Thus the trigger module provides a DAQ interface and transfers the encoders' data to the readout electronics for each trigger. The DAQ electronics packs this information together with detector data to from a complete slice data frame.

The DAQ interface is based on a generally defined high-speed differential serial links. If different DAQ electronics are used in certain product types, an adapter card is needed to convert the serial link to whatever the DAQ electronics asked for.

SCS connection

To configure the parameters and to monitor the status of the trigger module, like to set the work mode or to check the trigger rate etc, the trigger module is connected to the SCS (System Control Station) via the fast Ethernet link provided by the embedded controller.

Switch

Few switches are used to set the encoder types, the DAQ electronics types and other configurations.

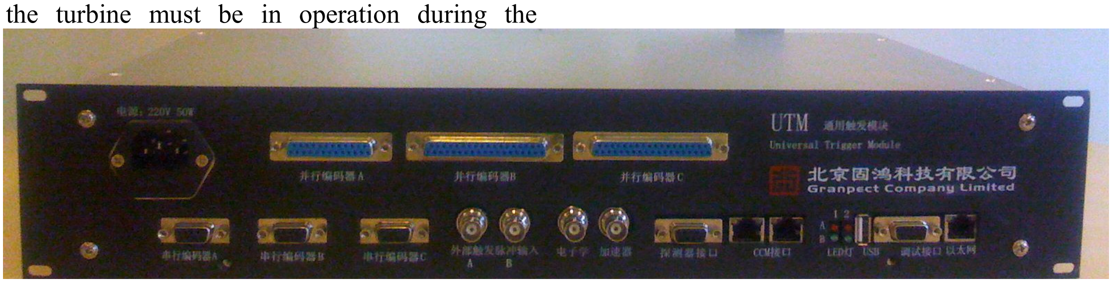

Figure 3: The front panel of the trigger module for industrial CT

EMBEDDED CONTROL MEZZANINE

All the logic and control functions are carried out in the embedded control mezzanine which consists of a processor running the Linux operation system and a FPGA device for the user specific firmware logic [2]. A description of the major items of the mezzanine is given below.

MPC5200 processor

The PowerPC processor from Freescale, MPC5200, with the necessary peripheral, memories and interface devices is the kernel of the embedded controller mezzanine, it has the following features:

- Running at 400MHz
- with 256MB DDR-266 SDRAM
- 16MB NOR flash memory for Linux kernel, file system and user application
- 100Mbps fast Ethernet connection
- Plenty of slow control interfaces like USB, CAN, IIC, SPI.
- Support Linux 2.4 or 2.6 operation system
- boot loader supported

The Linux operation system provides complete support for network protocol stack, file system, device drivers, multi thread communication and many other useful functional packages.

The process FPGA

The fast and real-time trigger process is implemented in a FPGA device, the EP2C35 from Altera. It provides enough logic elements and distributed memory for the industrial CT trigger logic.

The FPGA is configured in passive serial mode, the raw binary configuration file is stored in the NOR flash. After power up or reboot, the processor executes the u-boot code to read the rbf file and configure the FPGA accordingly. In this way, it is very easy to update the FPGA logic by downloading a new rbf file to the Linux file system via the Ethernet link.

Utilizing the local bus interface logic, The FPGA can be accessed by the PowerPC processor to change the configuration and check the internal information.

SCS client daemon program

A daemon service for the SCS communication is automatically latched after the Linux operation system is booted up. Two Ethernet sockets are created for sending commands and reading information. The daemon program has a simple command line interface that can be easily accessed from any computer via telent, ssh or even simple serial connection.

Self test and diagnostic feature

The embedded control mezzanine has several self test features to check the system integrality and interface connections.

- Each encoder signal is checked for the possible break or short connection. This is very useful for encoder cable and connection diagnostic.
- Self test of the trigger output and external input circuit with a loop back cable.
- A pseudo random counter can be sent through the DAQ interface to check the connection and the transition error rate.

SUMMARY

We have built a universal trigger module for the industrial CT product. The module collects the position and angle information from encoders and performs a trigger algorithm to deliver trigger signal back to the x-ray source and readout electronics. An embedded control mezzanine is utilized in the trigger module, which consists of a FPGA device to perform the trigger logic and a PowerPC processor running Linux operation system to provide Ethernet connection, FPGA configuration, and slow control. The design has shown great adaptability and flexibility for the industrial CT application.

REFERENCES

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[2] XUE Tao，GONG Guanghua，etc, The Design and Realization of General High--Speed RAINl00B DAQ Module Based on PowerPC MPC5200B Processor. NUCLEAR ELECTRONICS & DETECTION TECHNOLOGY, p186, 2010, 30(2)