RESEARCH ARTICLE | JANUARY 15 2019

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AIP Conf. Proc. 2054, 030036 (2019)
https://doi.org/10.1063/1.5084599

Design and Implementation of a Six-channel Embedded System for Reading Touch Sensors

Huai-San Wang[1,a)], His-Chou Ho[1], Chia-Jui Lin[1], Keng-Hao Hus[1], Shen-Yaw Perng[1], Tse-Chuan Tseng[1], Din-Goa Huang[1], Wei-Yang Lai[1] and Chien-Kuang Kuan[1]

[1]National Synchrotron Radiation Research Center, No. 101, Hsin-Ann Road, Hsinchu 30076, Taiwan

[a)]*Corresponding author: jeremyw@nsrrc.org.tw*

Abstract. Touch Sensors are used for precisely measuring displacements of the object of Taiwan Photon Source (TPS) Girder Control System (GCS). Therefore, a six-channel embedded system is designed for reading touch sensors with ENDAT 2.1 protocol. It is a portable and reliable equipment for simultaneously reading six touch sensors via the combination of digital implementation in a Field Programmable Gate Array (FPGA) chip and control software in a single-board computer. Thus, the embedded system can offer six input channels for touch sensors and its sampling rate reaches up to 1 KHz per channel. The embedded system also provides a web page to indicate the measurements and communicates between other devices by Experimental Physics and Industrial Control System software (EPICS). Finally, the six-channel embedded system for reading touch sensors reaches the satisfactory stability and high-speed transmission and is an easy-to-use multi-channel reader. This paper represents all design processes and structures of the six-channel embedded system.

INTRODUCTION

Many sensors are used in various industrial fields. The manufacturer only offers precise sensors and poor applications. Engineers and scientists are not easy to manipulate sensors to measure physical or chemical phenomenon. Therefore, the six-channel embedded system with touch sensors is designed to reduce measure problems and procedures at National Synchrotron Radiation Research Center (NSRRC). The main advantages of the six-channel embedded system divide three parts: (1) dramatically simplified programming and parameter configuration procedures, (2) automated record and (3) network display information. The first advantage can reduce complicated parameter setting and programming and users only focus on the data analysis. The second advantage can provide data storage by applying the EPICS tools and an open-source relational data management system (RDBMS) to store measurements automatically. The last is that users can directly use web browser to monitor measurements.

The goal of this paper is dedicated to construct a six-channel embedded system that makes all touch sensors be Internet of Things (IoT) sensors and to develops relative software. On the other hand, user can easily collect touch sensors data via the network. The relative work herein presents: (1) software development of the six-channel embedded system for touch sensors, (2) design and implementation of digital logic circuit and (3) VHSIC Hardware Description Language (VHDL) programming for transmission protocol.

SYSTEM ARCHTECHTURE OF THE EMBEDDED SYSTEM

The six-channel embedded system are divided into three components: (1) a single-board computer (2) a digital logic circuit and (3) touch sensors. The single-board computer provides rich peripherals, including Ethernet and general-purpose input/output ports, and a lot of third-party boards offering various applications. The single-board computer transforms touch sensors into IoT sensors. EPICS [1] software and control applications are also developed

Proceedings of the 13th International Conference on Synchrotron Radiation Instrumentation – SRI2018
AIP Conf. Proc. 2054, 030036-1–030036-5; https://doi.org/10.1063/1.5084599
Published by AIP Publishing. 978-0-7354-1782-3/$30.00

in the single-board computer. And the digital logic process unit carries out the communication protocol for the single-board computer and touch sensors. It consists of the digital differential signal transmission unit and a Field Programmable Gate Array (FPGA) unit. The digital differential signal transmission unit implements the differential signal transmission circuit between touch sensors and the FPGA unit. In according with clock signal, the FPGA unit transmits data signals of parameters to the touch sensors. Last components, touch sensors, take care to measure the object displacement. The six-channel embedded system is shown in Figure 1.

The main structure of the embedded system is shown in Figure 2. The single-board computer communicates with the digital logic process unit via serial peripheral interface bus (SPI) [2][3]. According to the parameters from the single-board computer, the position values or statuses of touch sensors in the memories of the FPGA chip updated regularly by the digital logic process unit are transmitted to the single-board computer.

Heidenhain length gauges are chosen as touch sensors and their transmission protocol, ENDAT 2.1 [4][5], is a half-duplex digital bidirectional interface. The differential signal transmission circuit is designed and implemented in accordance with ENDAT 2.1 specifications. Data (measured values or parameters) can be transferred in half-duplex mode between touch encoders and the digital logic process unit with transceiver components in accordance with RS-485 electrical interface (differential signals), in synchronism with the clock signal sent by the FPGA chip.

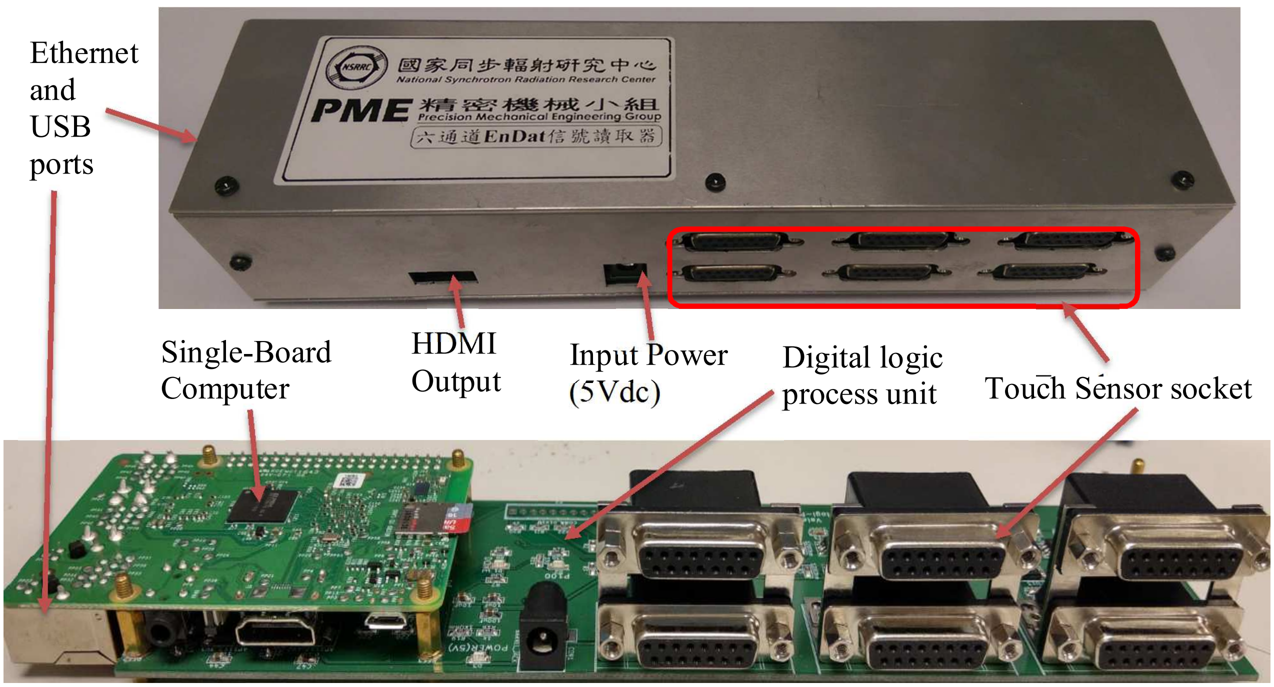

FIGURE 1. The six-channel embedded system for touch sensors consists of a digital logic process unit and a single-board computer. It provides six input channels for touch sensors, a HDMI port for connecting to a monitor and an Ethernet port for communicating with other devices.

SOFTWARE DESIGN OF THE SINGLE-BOARD COMPUTER

This section is dedicated to developing a software executing in the embedded system to transform all touch sensors into IoT sensors. The relative works are divided into four functions, as shown in Figure 3. The first function is designed to regularly read the position values of touch sensors via SPI and to put those data in shared memories simultaneously accessed by multiple programs. Base on SPI protocol, digital signals can be transmitted up to 200 MHz; thus, the refresh rate of data of touch sensors in the memories is up to 1 KHz. The second function in the single-board computer focuses on the transformation of a non IoT touch sensor into IoT one. The main advantage of IoT touch sensors is that measure data can be easily acquired by every device on a network. Therefore, users can efficiently collect measure data of IoT touch sensors. The single-board computer come with EPICS [6], and therefore the measure values of touch sensors are wrapped Input Output Controllers (IOCs) to be transferred to various computers.

The third function is designed to deliver web pages of the measured values of touch sensors to clients. The software are progamming by HyperText Markup Language (HTML), C language and Javascript language. The web server, NGINX, receives requests from clients and executes a Common Gateway Interface (CGI) script written by C language to read the data. And finally, data of touch sensors are delivered to clients' web browser in accordance with Javascipt language and HTML document rules. The web pages indicating the measured values is shown in Figure 3.

The last function focuses on the data storage. The MySQL database is adopted to store the data in the single-board computer. The measure values are regularly stored by EPICS tools. But the single-board computer does not support long-term retention because of the limitation of the size of data storage.

To achieve main functions mentioned, the single-board computer, Raspberry PI model 3, is chosen to complete the whole works because it offers an Ethernet port, four USB ports, general-purpose input/output ports, and various third- party boards offering rich applications. Linux is adopted in the single-board computer and software development environment on it is similar on the personal computer platform. Therefore, it is easy to develop a control program that manipulate the peripheral of the signal-board computers.

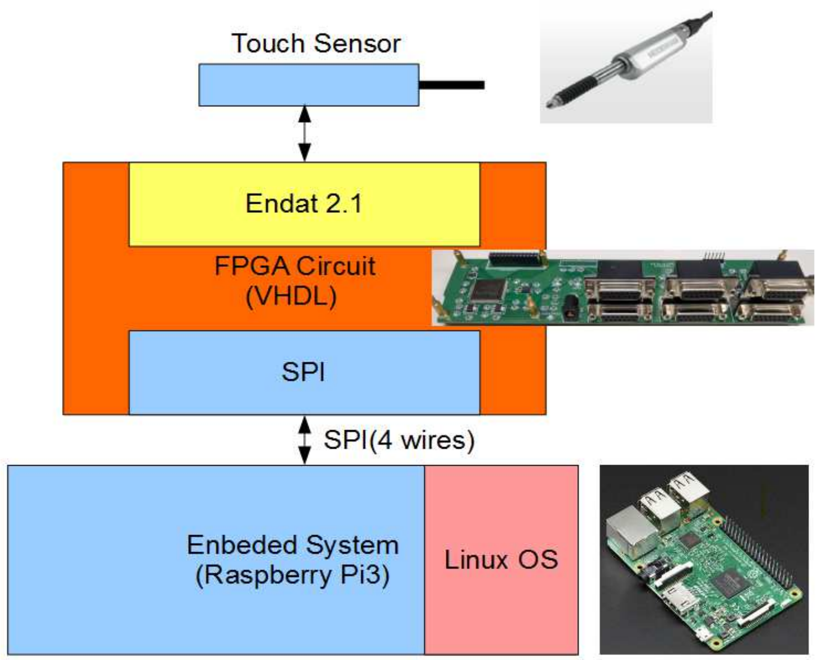

FIGURE 2. The single-board computer uses SPI protocol to reads measured values of touch sensors updated regularly by the digital logic process unit via Endat 2.1.

ARCHITECTURE OF THE DIGITAL LOGIC PROCESS UNIT

The digital logic process unit is a bridge between the single-board computer and touch sensors; thus, it reads measured values of touch sensors and responses to the single-board computer. The printed circuit board of digital logic process unit is designed and implemented as shown in Figure 4. FPGA is suitable to implement complex digital computations. Therefore, a FPGA chip is applied to implement SPI protocol and ENDAT 2.1 protocol for communicating with the single-board computer and touch sensors respectively. Based on SPI protocol, the transmission data formats are well defined and relative programs are developed VHDL. Because SPI transmission is a kind of synchronous serial interface, the FPGA chip also defines four pins as the clock pin (output from the master), the receiving pin (data output from the master), the sending pin (data output from the slave) and the slave select pin (output from the master) for electrical interface bus. The single-board computer (the master) enables the slave select pin to activate the FPGA chip (a slave device) first and then sends synchronous clock to the FPGA chip for the transmission speed. The FPGA chip receives the instructions and transmits the measured valued to the single-board computer by receiving pin and the sending pin respectively.

The FPGA chip also communicates with touch sensors to update the measured values in the memory simultaneously by using ENDAT 2.1. The refresh rate of the measured values of touch sensors in the single-board computer can reach 1 KHz with Heidenhain length gauge, AT1218. According to Heidenhain manual, ENDAT 2.1 is a digital, bidirectional interface standard for position or rotary encoders. It defines two pair differential signals for bidirectional differential data and the differential clock signals. Thus, one pair of differential data signals are employed to transmit or receive the data in synchronism with the other pair of differential clock signals at 200 KHz generated by the FPGA chip. The yellow line and green line, observed by an oscilloscope, are the synchronous clock and the transmitted data signals respectively, shown in Figure 5.

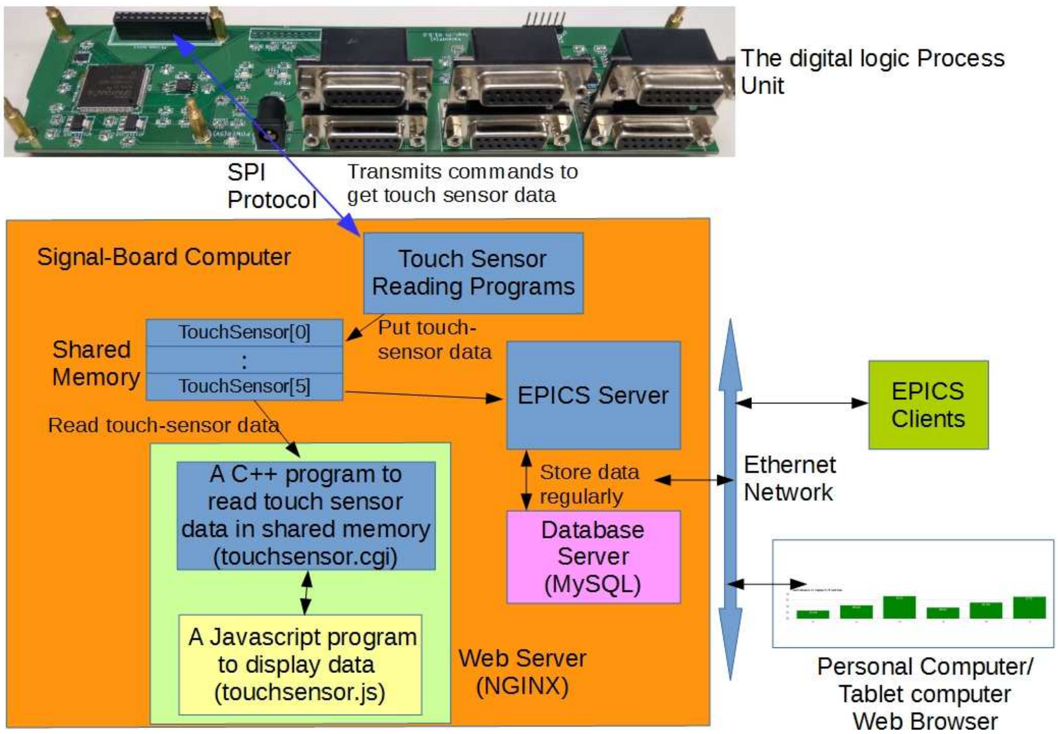

FIGURE 3. The single-board computer transforms touch sensors into IoT sensors by using EPICS library. The main architecture of the single-board computer includes a reading program, an EPICS program, a web program and database server.

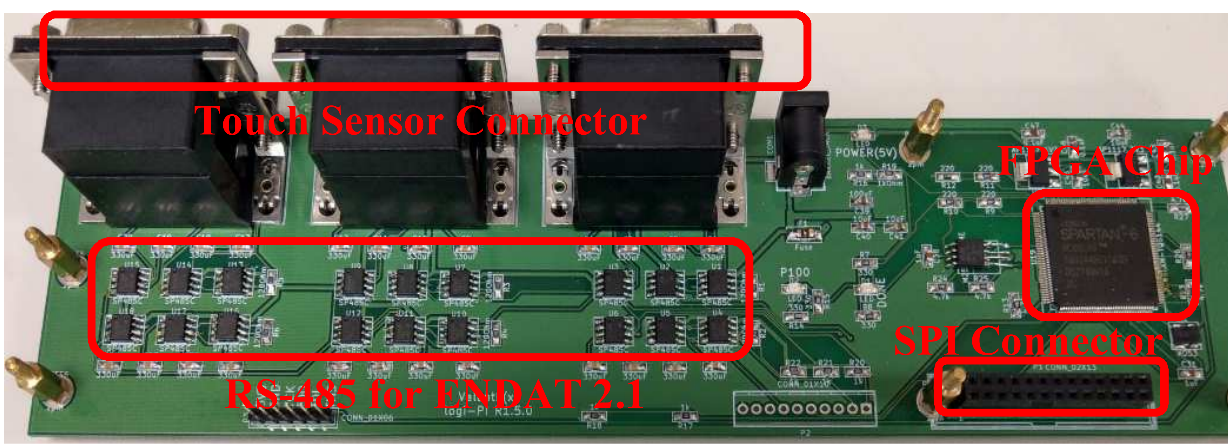

FIGURE 4. The printed circuit board includes a FPGA chip for implementing complex digital computation and the RS-485 circuit for differential signal transmission.

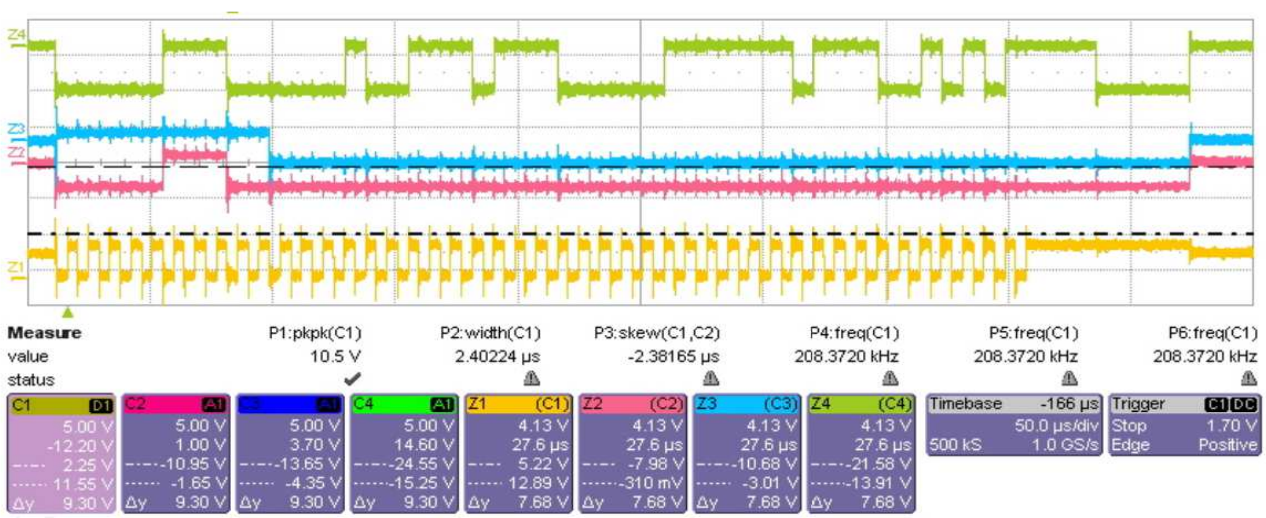

FIGURE 5. The yellow line and green line are the synchronous clock and transmitted data signals respectively.

Summary

The six-channel embedded system provides a total-solution for sensing mechanical displacement. It transforms non IoT sensors into IoT ones and adds many useful facilities to reduce complicated programming and parameter configuration processes. User can efficiently obtain measure data by using IoT sensor via Ethernet and this is a lack of non IoT ones. The remote computers also receive data on web pages from the embedded system. Nowadays, the embedded system with AT1812, Heidenhain length gauge, can refresh rate of the measure values up to 1 KHz and provides high resolution grade of 23 nm. Finally, the six-channel embedded system for reading touch sensors has the satisfactory stability and high-speed performance and is an easy-to-use multi-channel reader.

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