The design of a portable seismograph used in aftershock seismic array observation

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Abstract. This paper introduces the design of a portable wireless-linked seismograph used in aftershock ultra-dense seismic array observation, which features easy-to-install, low-power consumption, real-time data transmission and remote control capability. Compared to traditional instruments, such as the combination of Reftek 130s data recorder and Guralp CMG-40T seismometer for China Seismic Array Program, it integrates the seismic sensor, seismic data recording unit, GPS timing service and wireless data link into a compact sealed housing. To verify the system’s functionality, both laboratory testing and preliminary field experiments were conducted. The exceptional feature of this newly-developed portable wireless-linked seismograph makes it very suitable for aftershock seismic array observation.

1. Introduction

In recent years, upon the occurrence of strong earthquakes in China, Geophysical Exploration Center of CEA rapidly start up the earthquake emergency observation response and researchers were sent to the earthquake region to do aftershock monitoring [1-3]. Substantial valuable raw seismic data are collected for being used in research on focal mechanism and seismogenic fault. The device used in aftershock monitoring is the portable digital PDS seismometer, which features lightweight, compact volume, easy to install and convenient operation. The working mode of using PDS Seismometers is that after deploying the device and conducting observation for one week, the devices will be taken back, then download the seismic data and do data processing work. Then, next circle begins. This working modes leads to a lag for obtaining the dynamic seismic regime [4-8]. Therefore, in order to realize the real-time monitoring of aftershock seismic activity of earthquake region, and provide the tehcnological observation measurements for researchers. A new portable wireless-linked seismograph used in atershock seismic array observation has been developed.

2. Development of the portable seismograph

The instrument system is mainly composed of portable wireless-linked seismograph, remote control server on the PC and back-up power (storage battery, or solar power supply system). The seismograph is designed to do the work of data acquisition, analog-digital conversion, seismic data storage and remote data transmittion and control, etc. On the top cap, there are 2 antennas, one for wireless connection to the 4G mobile communication network and the other for GPS message receiving. The remote control server, running on the personal computer, is the operating interface between users and seismographs, which has the ability of setting up and checking the device working parameters,
inquiring the instrument working states etc. The seismograph has a built-in lion battery, but in the
case of continuous aftershock seismic array observation and turning on the wireless transmission
function, the built-in battery is not enough. Thus, it is essential to equip with back-up powers, such as
large capacity storage battery, or solar power system. The GPS reciever provides time service and
geographical position information. Compared to the now available seismographs, such as Reftek 130
and Guralp CMG-40T systems, used in aftershock seismic array observation for megaseisms, this
seismograph features low-power, compact volume and easy to operate and deploy. Figure 1 shows the
block diagram of the seismograph system.

2.1. Hardware design of the seismograph
The seismograph mainly consists of data acquisition unit, seismic sensor, wireless transmission unit
and built-in li-ion battery. All function blocks are integrated in a compact shell with the wireless
antenna and GPS interface installed on the top cap.

2.1.1. Data acquisition unit. The data acquisition unit, whose core MCU STM32F407 [9], mainly
fulfill the analog to digital conversion of the seismic wave, GPS timing service and geographical
location, data storage on the CF card, USB communication interface, RS-232 control interface. As
showed in Figure 2.

The seismic sensor converts the velocity of ground motion to electrical signal, which pass through
the front-end analog signal conditioning circuit and finally in the form of differential signal feeds into
the analog-to-digital converter. In this design, there are three independent A/D channels used to
convert the seismic wave of NS, EW and UV directions to 24bit digital words. The ADC used is the

![Figure 1. Block diagram of the instrumentation system diagram.](image1)

![Figure 2. Data acquisition unit block.](image2)

![Figure 3. ADS1282 application design circuit.](image3)

![Figure 4. CF card interface circuit design.](image4)
Analog Devices product ADS1282 [10], very suitable for high-precision, low frequency, feeble seismic signal conversion. Utilizing the SPI interface, ADS1282 makes connection with the core MCU, and on the bootstrap stage the firmware running on MCU initialises the gain, sampling rate of the ADC. ADS1282 features excellent low power consumption and is specially fit for usage in portable measuring systems. The application design circuit is as showed in Figure 3.

This seismograph uses CF card as the seismic data storage media, which have the advantages of miniature, high-capacity and low-power [11]. In order to nicely satisfy the requirements for severe environment of field seismic data acquisition, industrial grade CF card is adopted and its working temperature ranges between -40°C-85°C. In this design, by making use of the FSMC of STM32F407 to generate the bus timing for TrueIDE interface, the system realizes the read and write access to CF card, as showed in Figure 4. Besides, the seismograph has a local data-downloading interface through USB device interface. Using the USB cable to connect the seismograph to a lap-top computer, the application software running on the computer can do many operations, such as working parameters setting, running state polling, and access to raw seismic data files, etc. The USB controller is used to realize the function in this design [12], as showed in Figure 5.

The seismograph integrates a GPS module to synchronize the system software clock and obtain the geographic information, including the Longitude, latitude and altitude of the observation station. The power supply of the seismograph is composed of built-in high capacity Li-ion battery and backup storage battery, or solar power supply. The power supply voltages of all function modules are generated from LDO circuit, including the voltage of MCU Vcore = 1.8V, ADC reference Vref=2.5V, CF card Vcf=3.3V, and TCXO Vco=3.3V [13].

2.1.2 Seismic sensor. The seismic sensor is an electromechanical device used to convert the velocity, displacement or acceleration of the ground motion to electrical signal, also known as seismometer. The seismometer used in the design is a velocity output passive transducer CDJ-6B, which can pick up the ground motion velocity of NS, EW and UV directions. The seismic sensor has a natural frequency 2.5Hz, internal resistance 5.6kΩ, sensitivity 200V·S/m. In order to collect more low frequency content of aftershock observation, it is necessary to extend the corner frequency of CDJ-6B as low as possible, a low frequency integral method, which is accomplished through balanced integration and high precision chips to suppress the circuit drifting and noise interference, was used to extend the CDJ-6B’s frequency response. The low corner frequency is extended from 2.5Hz to under 0.1 Hz, and the sensitivity is enhanced from 200V·S/m to 300V·S/m. The -3dB Bandwidth is tested on the low-frequency shaking table, the amplitude frequency characteristic curve is as showed in Figure 6.

2.1.3 Wireless 4G module and GPS service. The seismograph has the function of remote real-time data transmission and remote control. By means of the antenna, the wireless module makes a data connection based on the 4G data service to mobile communication networks, and eventually establishes a virtual communication data link with the monitoring computer on the Internet [14]. In software design, the wireless module firmware interacts with the monitoring application software in the
pattern of client/server mode. Upon the power on, the seismograph initiates the connection request to try to setup a data communication link with the monitoring computer. On the other end, the monitoring application server located in the monitoring center listens the connection request on designated port. Once the wireless connection successfully established, we can do the same operations as what we do using the local USB port. The LEA-6T module is used for GPS service [15-16], and all-direction antennas are used to ensure the harsh observation environment [17].

2.2. Firmware and application design

The software of this seismograph includes two parts. One part is the firmware running on the seismograph MCU, which mainly finishes the data sampling, FIR/IIR filtering, GPS message interpretation, data communication, data storage control, etc. The other part is the monitoring application server running on computer, by which the users can do operations on the seismograph.

2.2.1. Firmware. The firmware is composed of many software function modules, such as control commands processing, communication parameters configuration, sampling parameters control mechanism, seismic data FIR/IIR filtering and CF card drivers. All the firmware codes are developed by ARM C and assembly languages, which leads to several advantages, such as cutting down MCU frequency and furthermore reducing the system power consumption, and saving storage space for firmware codes. The firmware structure is as showed in Figure 7.

2.2.2. Monitoring application software. The monitoring application software running on PC is used to realize the remote control on the seismograph. When the remote data link is established between the seismograph and the monitoring application, users can conveniently do many operations on the seismograph, such as working parameters configuring, presetting the sampling schedule, filling in station geographical notes, checking working status, and real-time seismic wave display, etc. The Monitoring Application software is as showed in Figure 8.

3. Preliminary testing and field experiment results

Preliminary testing has been conducted on the developed prototype seismographs, which are as showed in Figure 9. The several key performance indexes of the testing results of the prototype seismographs are as follows: -3dB Bandwidth: 10s -100Hz; Dynamic range: > 132 dB; Self noise: -140 dB (Relative to 1 [m/s-1]^2 Hz-1); Digitiser resolution: 24-bit; Sample rates: 50, 100, 200, 250, 500, 1000; Output data Format: MiniSeed; Triggering modes: STA/LTA, level, software; Internal storage capacity: 32 GB CF card storage (Non-hot-swappable); Power consumption: 450mW; Adjustable gain: 2^0~2^7; Operating temperature: -20 to +65℃. Some preliminary field experiment, which makes use of the artificial seismic sounding prospecting project in October 2020, validates the basic functions and suitability for seismic array observation. The profile result is showed in Figure 10. A thorough comparation experiment with other well-known seismic systems is planned to be done in the second half of the year.
4. Conclusions and discussion
The development of this portable wireless-Linked seismograph intended for use in aftershock seismic array observation has basically finished, which achieves a good balance and trade-offs between seismograph’s performance and portability. This seismograph features miniature, low power consumption, and low-cost compared to the Reftek 130s and Guralp CMG-40T systems. It is very suitable for usage in aftershock dense seismic array observation. More thorough testing and field experiments will be conducted, through improving the hardware and software designs to further enhance the instrument stability, reduce power consumption, cut down transmission delay and extend the corner frequency even lower. Continuous efforts will be also devoted to upgrade the system for real-time data transmission applications, such as large scale dense arrays for ambient noise observations.

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