Skeleton Seismometer for Classrooms

–Using Acrylic Plates, Neodymium Magnet and ESP32 Board –

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日本地学教育学会

日本地学教育学会第77回全国大会滋賀大会
2023年度全国地学教育研究大会

OBJECTIVES （研究の目的）

i) Develop seismographs that are easy to understand the principle and structure of seismographs to be shown in the classroom.
ii) The seismograph can be used for practical observation of natural earthquakes, constant microtremors, and environmental vibrations.
iii) The level of construction should be simplified as much as possible so that even high school students can make it by themselves.
iv) The cost should be less than 10,000 yen for a single-component seismograph, using acrylic resin scraps and neodymium magnets, etc.
v) We will try to update the amplifier and recording system.

SEISMOGRSPHS（地震計）

1. Pendulum

<Horizontal motion> The swing gate type (Paschwitch type) used in conventional seismographs is employed.
A 5-mm-thick acrylic plate made of acrylic resin end material (hereinafter referred to as "acrylic end material") is cut using an acrylic cutter. Assembled with acrylic adhesive and 4mm screws. The weight of the pendulum is added by adding a laminated circular neodymium magnet and a lead plate as an increment of the mass.

<Vertical motion> The Kirnos type used in the previous model (3D printer seismometer, Okamoto 2022) is employed. The manufacturing of the housing is the same as that for the horizontal movement. The difference is that piano wire coil springs are used. To extend the natural period, a spring fabricator was asked to shorten the initial length of the spring. The most notable feature of the new model is the elimination of the complicated structure of the cross spring, which was previously used as a fulcrum. Instead, a single thin plate spring is placed in the direction of the tension vector of the main spring. This simplified the construction (see Fig. 1 and Fig. 4).

<Pillar> Glued with 5mm-thick acrylic plates, respectively. Bolted. Be careful of the gap width when gluing so as not to restrict the movement of the pendulum.

<Fulcrum> Use a 4mm wide, 0.1mm thick sheet of phosphor bronze (C5210?) for the spring, leaving a gap of 3.5 to 4mm. The clamp is made by a 3D printer, and the spring is fixed with a 4mm screw.

The overall structure of the seismograph is shown in Fig. 1.

2. Magnet Circuit

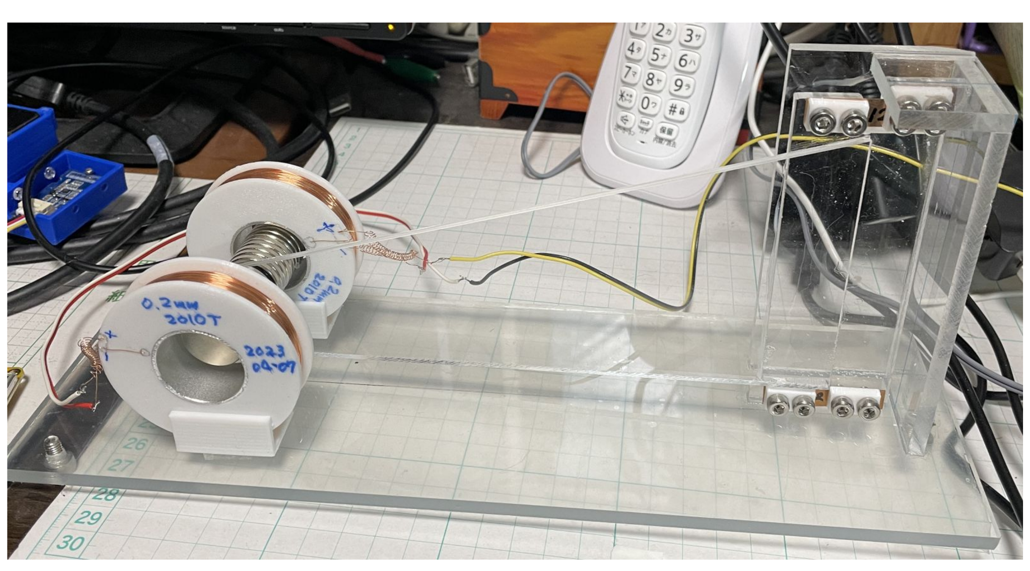
<Magnet> The required number of circular NdFeB magnets (φ20 mm, 5 mm thick), which also serve as weights for the pendulum, are stacked and attached to the thin acrylic plate of the pendulum by magnetic force alone. The direction of the magnetic field is the same on both sides.

<Coil> Wind a urethane wire of 0.2mm to 0.26mm about 2000 times. Bobbins (inner diameter 30mm, outer diameter 60mm, inner width 10mm) are made by a 3D printer. Fig. 2 shows the winding of a coil.

<Magnetic circuit configuration> Magnets with the same pole direction are arranged horizontally (horizontal movement) or vertically (vertical movement). By combining these with coils of the same winding direction, the signals of the two sets of magnetic circuits are multiplied. By combining two sets, even if the pendulum is shifted to either side, the signal strength is expected to compensate for each other. This is the same method used in the previous model (Okamoto, 2022a).

3. Body part

The body is also assembled using the above method from a 5 mm thick acrylic plate. An 8x8mm piece of acrylic bar is glued to the bottom of the floor material for reinforcement. The horizontal motive material is bolted to the flooring material to adjust the tilt. The goal is to achieve a natural period of about 3 seconds for both horizontal and vertical movements. This is considered to be the minimum requirement for detecting earthquakes with a reasonable sensitivity in foreign countries where long-period earthquakes are predominant.



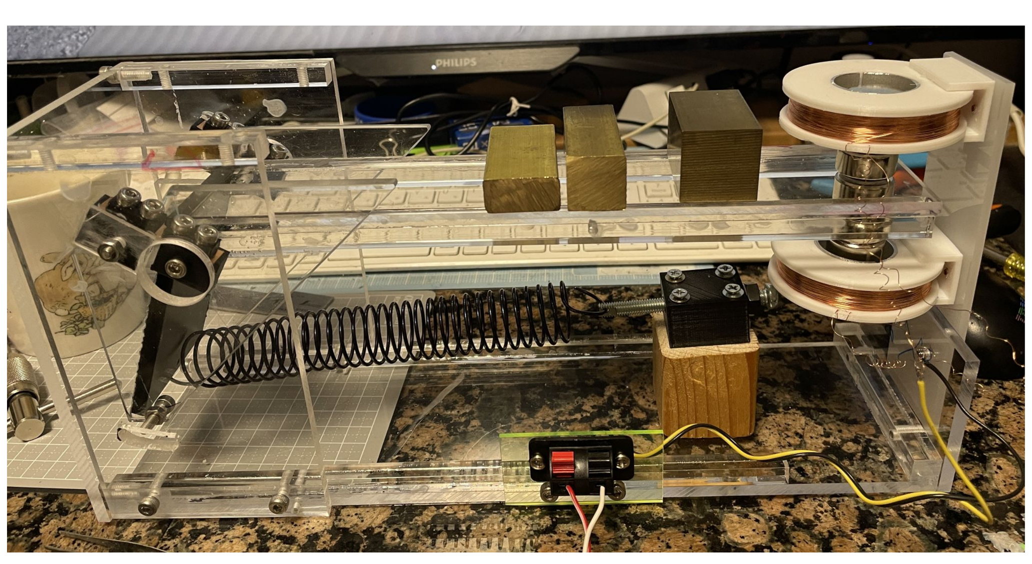


Fig.1 Horizontal pendulum (upper) and Vertical pendulum (bottom

Fig.2 Hand coil winder with counter. Now 0.25mm urethane coil is winding

INTEGRATED AMP（観測用アンプ）

The amplifier that amplifies the signals from the micro coils is based on the single power supply (5 V) amplifier circuit of the author's ANB seismometer (Okamoto, 2015), with some modifications. The circuit diagram is shown in Fig. 3.

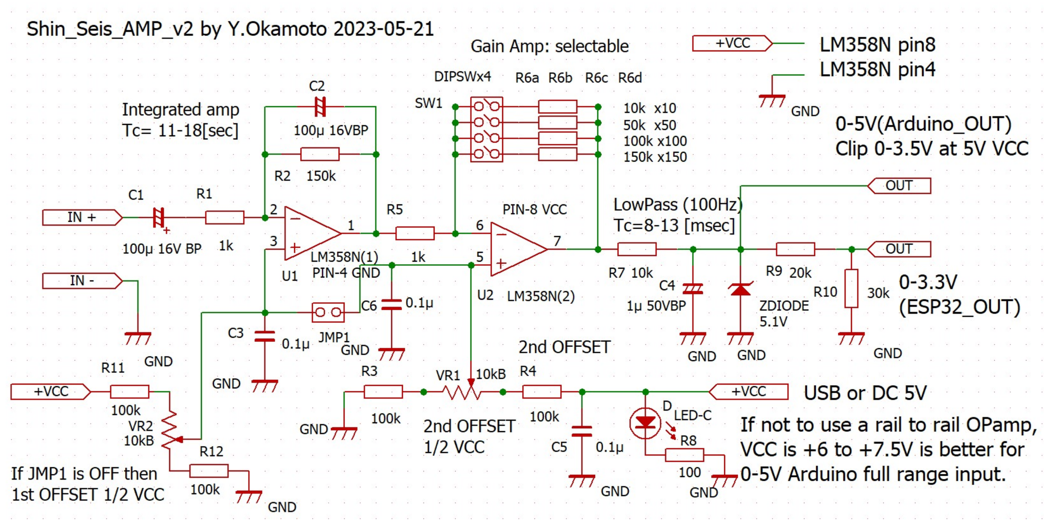


Fig.3 An integrated amplifier for our system(1ch) . The time constant for the integration is around 30 sec

DATA LOGGER （記録装置，試行）

<Introduction> We selected a recording device for high school students to make a microbarometer within the range of their allowance. First, the RaspberryPi, which has been used in the author's microbarometer (Okamoto, 2022), but costs more than 10,000 yen including the LCD monitor. Next, we checked M5Stack, which was also used in the microbarometer. The price and size are sufficient, but the monitor size and sampling speed are not good enough for a seismograph. Finally, I found an ESP32 MC (microcontroller) board with LCD.

<ESP32 board with LCD> The ESP32 is a popular MC in the field of measurement, and is also used in the M5Stack mentioned above. Substrates with LCD monitors are available at low prices through mail order in China. The following two types of boards were tested.
ESP32-3248S035 (with 3.5" LCD 320x480, approx.
2400-2800 yen, price varies depending on LCD type)
ESP32-8048S043 (with 4.3" LCD 800x600, approx.
The price varies depending on the LCD type).
The resolution is different and the pin assignments are also slightly different. Although it is a small board, it is a multifunctional ICT item with A/D conversion, wifi reception (JST clock synchronization), and data storage on SD card. This small board can replace a conventional Arduino + PC logger.

However, there is very little information available at this time, and it was very difficult to make a prototype. However, considering the price, it is a very promising MC for use in teaching materials in the future, along with RasPi and Arduino. The advantage is that the cost of production can be significantly reduced.

However, the disadvantages of the MC for use in seismographs are its slow sampling rate and the long time required to write data to SD. However, if only one channel is used for high school students, the sampling rate of about 20-30 Hz can be achieved. However, if a high sampling rate is required for 3 channels, the conventional method using an Arduino + PC is the best.

<Software> The ESP32 boards can be used by including various libraries for driving the ESP32 in ArduinoIDE (all free of charge). However, as mentioned above, be careful with the board information.

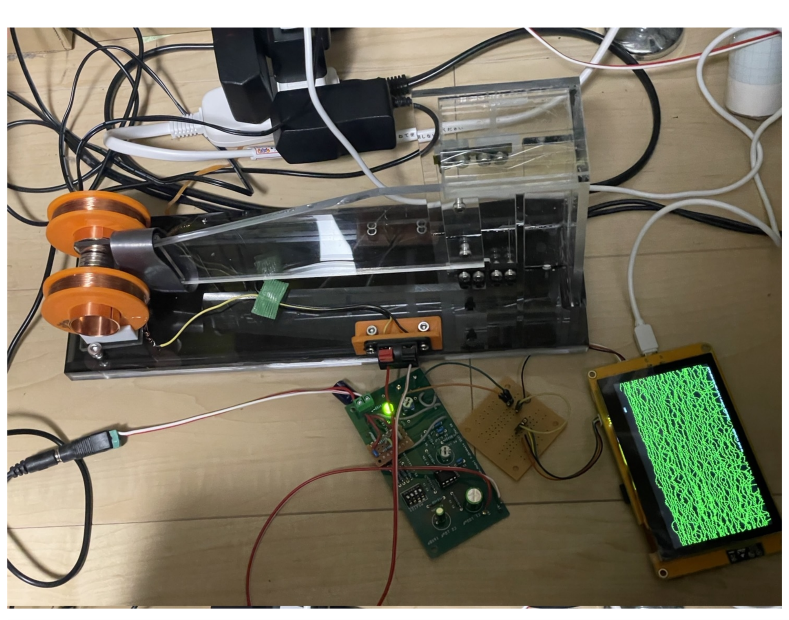
As mentioned above, A/D conversion for each channel and data saving to SD card are available. The control program including the screen display will be available on the author's Web site. The following shows the data recording using this board and a record of a seismic event.

<Recording by Arduino + PC > The ESP32 is small and inexpensive, but its sampling speed is not good. Therefore, the use of ESP32 is temporarily suspended and the conventional Arduino + PC observation system (Okamoto, 2015) is used again. The ESP32 system is very effective for "microbarometer" (Okamoto, 2022b), where a slow sampling rate is sufficient, and will be presented in detail at another time.

OBSERVATION SITES（観測サイト）

In the closet at home (first author, Okamoto):
The ESP32 system is a prototype system and has been discontinued. Here are some photos of the recording system using an ESP32 (800x480 LCD board). The recording screen of nearby earthquakes is also shown.

Observation in Thailand:
From the end of August, the above system will be transferred to several universities in the northern part of Thailand for observation. We are planning to build several sets of test observation equipment, so please contact us if you would like to borrow them.



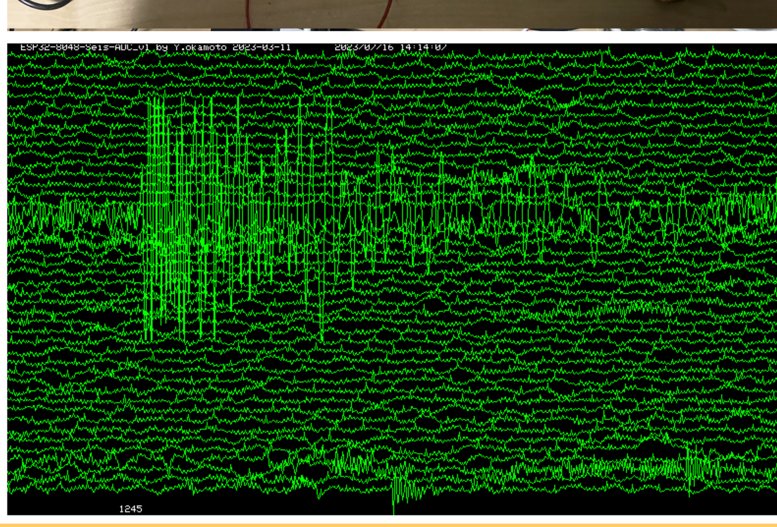


Fig.4 Observation site of my house: 2F closet. Using Esp32+LCD and mono power OP amp (upper).

A felt earthquake (Nara Pref. M4.0 h=70km) is recorded with ESP32+LCD system. LCD captured image (bottom).

DATA & RESULTS （データ・観測記録）

An aftershock of M5.9 of Noto Pen. (M6.5 May 5, 2023)
May 14, 2023 earthquakes near Hachijojima Island

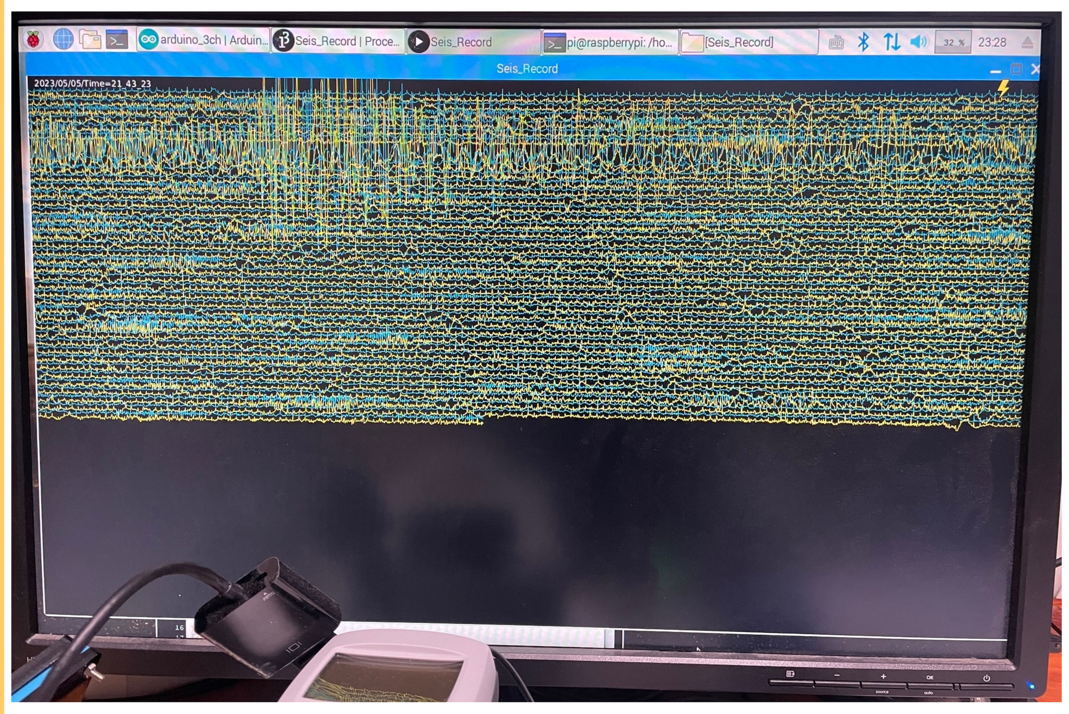
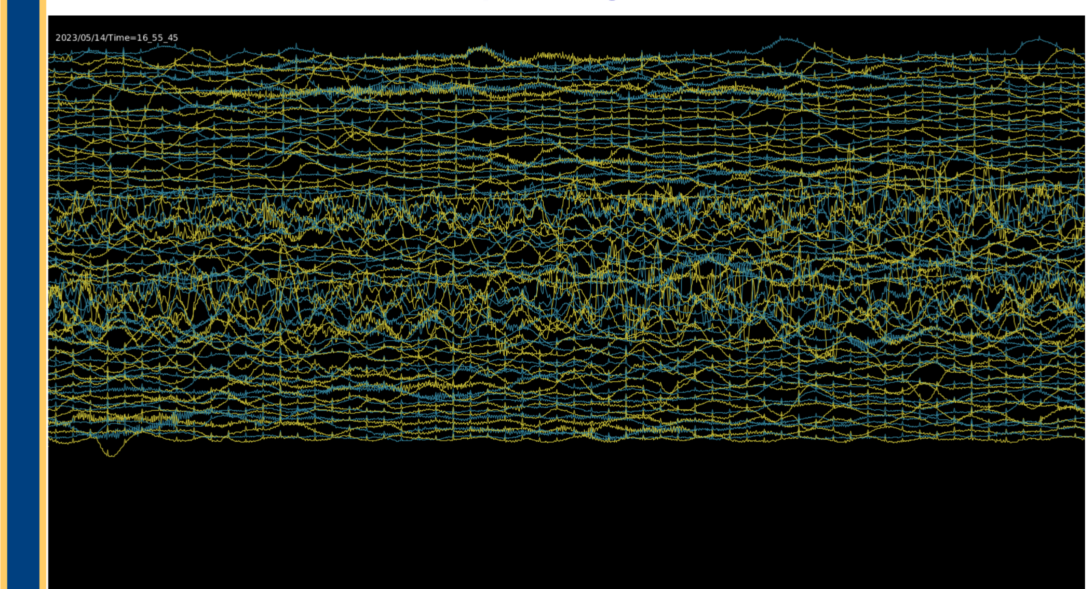


Fig.5 An aftershock M5.9 of Noto EQ(M6.5 2023-05-05) recorded with Raspberry Pi system. Time mark is 1 second. You can see clear short period ground motions.



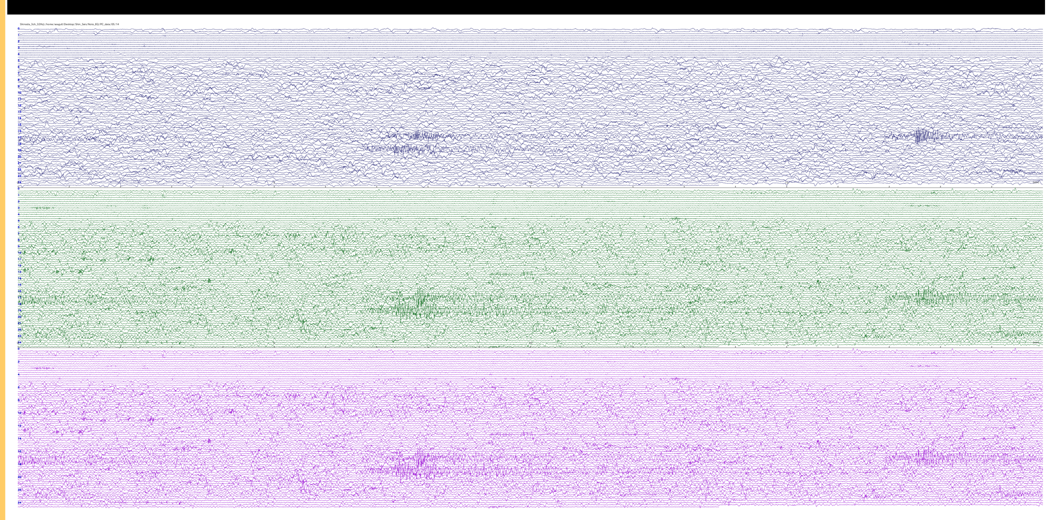


Fig.6 Near Hachijojima M5.6 and M5.9 2023-05-14 recorded with PC system. Up: PC realtime image.16:55 pm start 14th May 2023 Bottom: Daily record of the same day

DISCUSSIONS （議論）

1. Acrylic sheet crafting skills are required. the bulk price is low.
2. The weight is a little too light, so additional weight is need ⇒A lead plate can be added to make up for this.
3. The acrylic plates are glued with an adhesive (dichloromethane), which is strong enough. However, adjustment is difficult. So bolting is also used.
4. The coil winding machine increases the efficiency of coil fabrication.
5. The FSB board was out-sourced, making it inexpensive and easy to assemble. The amplifier can be used with a 5V single power supply.⇒ However, it is difficult to adjust the offset at high gain, so we are trying to solve this by trial and error.
6. ESP32 has too late sampling rate, therefore it is not suitable as a seismic logger. (it is useful for a microbarometer).
7. However, it is effective for only 1-channel recording at a sufficiently low cost.
8. The Raspberry Pi system is relatively expensive, but its merits are small.
9. We are hoping for the establishment of a seismic network by students of high school geoscience clubs.

CONCLUSIONS （結論）

1.The skeleton fabric shows well how the seismometer works.
2. However, difficulties were found in the new recording system with a single power supply OP amplifier and a small microcomputer ESP32. Critical offset adjustment and the low performance of the ESP32 operation.
3. It is useful to use as a single-channel logger.
4. Our new suspension of the vertical pendulum was successful.
5. We would like to improve the above problems and evaluate the performance in the future.

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Out sourcing of PCB
JLCPCB https://jlcpcb.com/VGB
PCB/Gerber Editor: Minimal Board Editor (Japanese only):
https://www.suigyodo.com/online/mbe/manual/set/set.htm
An alternative for foreigners: KiCAD:
https://www.kicad.org
Earthquake data from JMA and USGS
ESP32Board Details: Website in Japanese
https://macsbug.wordpress.com/2022/10/02/esp32-3248s035/
https://macsbug.wordpress.com/2022/11/29/esp32-8048s043/
First Author Website: http://www.yossi-okamoto.net/

ACKNOWLEDGMENTS （謝辞）

大阪教育大学附属高等学校天王寺校舎 物理・地学実習助手，三橋れ氏には地震計製作にあたり，数多くの有益な助言をいただいている．タイVISTECのDr.Thanit Pewnim氏には，タイでの筆者の活動について，常に便宜をはかっていただいている．両者に感謝します．

Mr. Rei Mitsuhashi, Laboratory teacher of Physics and Earth Science, Osaka Kyoiku University Senior High School, Tennoji, Japan, has given me a lot of useful advice on the construction of the seismograph. Dr. Thanit Pewnim of VISTEC, Thailand, has always been helpful to me in my activities in Thailand. I am grateful to both of them.