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Design A Prototype of Temperature Logging Tools for Geothermal Prospecting Areas

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Abstract

The costs of geothermal exploration are very high because technology is still imported from other countries. The local business players in the geothermal sector do not have the ability to compete with global companies. To reduce costs, we need to develop our own equipment with competitive prices. Here in Indonesia, we have started to design a prototype of temperature logging tools for geothermal prospecting areas. This equipment can be used to detect temperature versus depth variations. To measure the thermal gradient, the platinum resistor temperature sensor is moved slowly down along the borehole. The displacement along the borehole is measured by a rotary encoder. This system is controlled by a 16-bit H8/3069F microcontroller. The acquired temperature data is displayed on a PC monitor using a Python Graphical User Interface. The system has been already tested in the Gunung Pancar geothermal prospect area in Bogor.

Abstrak

Perancangan Prototipe Alat *Logging* Temperatur untuk Area Prospek Panasbumi. Biaya eksplorasi panasbumi tinggi dikarenakan teknologi yang masih diimpor dari luar negeri. Akibatnya, pelaku bisnis panasbumi dari dalam negeri sulit bersaing dengan perusahaan asing bermodal besar. Dalam upaya menekan biaya eksplorasi, kami merancang alat ukur gradien suhu di lubang sumur eksplorasi panasbumi dengan biaya produksi yang relatif terjangkau. Alat ini berfungsi untuk mengukur peningkatan suhu sebagai variasi terhadap kedalaman. Untuk mengukur gradien suhu, sensor Pt-100 diturunkan ke dalam lubang sumur secara perlahan-lahan. Penambahan kedalaman posisi sensor Pt-100 diukur menggunakan sensor *rotary encoder*. Alat ini dikendalikan sepenuhnya oleh mikrokontroler 16-bit H8/3069F. Data suhu hasil pengukuran ditampilkan pada layar monitor menggunakan *Graphical-User Interface* dengan bahasa pemrograman Python. Alat ukur gradien suhu ini telah diujicoba di daerah prospek panasbumi Gunung Pancar, Bogor.

Keywords: borehole, geothermal, gradient temperature, logging, prototype

1. Introduction

Borehole temperature measurement has already been used for many earth science research areas. It is an important parameter in the analysis of resistivity logs, the detection of submarine heat flow [1], the analysis of fracture rock formations [2], sedimentary basin modeling [3-5], and geochemical modeling of formations for the analysis of hydrocarbons maturity and for the analysis of climate change [6].

Meanwhile, for geothermal exploration, the determination of the static formation temperatures from temperature-depth measurements constitutes a crucial task for the evaluation of geothermal systems. Temperature-depth measurements in wells are used to determine the geothermal gradient [7] and the heat flux density [8]. For example, Kutasov and Eppelbaum [9] have developed a method for estimation of geothermal gradients from a single temperature log. Now days, the neural network method has also been used for analyzing borehole temperature data [10].

In Indonesia, since crude oil production has been declining, the Indonesian goverment is encouraging the use of geothermal energy as a substitute for oil. In fact, Indonesia has abundant sources of geothernal energy because of its location right on the Ring of Fire that circles the Pacific Ocean [11]. Geothermal areas are located across the archipelago from Sumatra and Java-Bali to Sulawesi, Maluku, and Nusa Tenggara [12-13].

However, the costs of geothermal exploration are very high [14]. Especially for Indonesia, where the technology for exploration and drilling are still imported from other countries, the costs will be even higher. The local players in the geothermal business will have less ability to compete with global companies. To reduce those costs, we need to develop our own equipment with competitive prices. Here in Indonesia, we have started to design a prototype of temperature logging tool for geothermal prospecting areas.

In an area where there is no geothermal manifestation, the normal conductive temperature gradient is about 3 ^{o}C/100 m [15]. Meanwhile, in a prospective geothermal area, the thermal gradient is several times greater than normal. To measure the thermal gradient, a platinum resistor Pt-100 for temperature sensors is moved down along the borehole. Xu *et al*. 2010 have already used a Pt-100 temperature sensor for measuring the geothermal gradient in the Shincuan Basin, China [16].

Our system is controlled by the 16-bit H8/3069F microcontroller manufactured by Renesas Corp., Japan. We have used this kind of microcontroller to anticipate complex features that will be built in the future. The measured temperature is displayed on a PC monitor using a Python Graphical User Interface.

2. Methods

The instrumentation system of the temperature logging tool that we designed is shown in Figure 1. The microcontroller H8/3069F, as the core of system, has one analog input (i.e. temperature sensor) and one digital input (i.e. rotary encoder).

The temperature sensor used in the system is a Pt-100 platinum resistor. These kinds of platinum resistance thermometers are remarkable instruments. In various forms they operate over the range of −260 °C to 960 °C, with accuracies approaching 1 mK [17]. The Pt-100 is functioned to measure underground temperature variations along the borehole. Being a resistance thermometer, the Pt-100 requires external stimulation in the form of a voltage. We use a voltage divider configuration to stimulate a voltage and the voltage is amplified by a LM324 device. After that, the amplified analog output is converted into digital by a 10-bit ADC (Analog to Digital Converter) before entering into the microcontroller.

The rotary encoder is functioned as a depth sensor along the borehole because its rotation can be converted into displacement. For this design, we used a rotary encoder (E40S6-1000-3-T-24) made in Korea [18]. An interrupt connection is used by the microcontroller to receive digital output from the rotary encoder.

The 16-bit H8/3069F microcontroller manufactured by Renesas Corp (Japan) incorporates a 512 Kbyte flash/16 Kbyte SRAM memory [19]. The microcontroller is functioned to control the real-time input data flow from the temperature sensor and rotary encoder to the computer. RS-232 as a serial data transfer protocol is used to send the acquired data from the microcontroller to the computer. Finally, the acquired data is stored in the computer's hard disk based on the ASCII format.

Besides the instrumentation system, we have also constructed a mechanical logging stage. It is used to hold the temperature sensor, including its cable and rotary encoder, during data acquisition in the borehole. The cable, which has a length of 100 m and weight of 5 kg, should be held by a mechanical logging stage during temperature logging.

Regarding data visualization, we have developed a Graphical User Interface (GUI) using the Python programming language. We have chosen Python because it offers the dual benefits of rapid prototyping and ease of comprehension, which in turn allows for the quick creation of sophisticated tools for a diverse range of instrumentation applications [20]. Through GUI, we can also control the system for starting or stopping the data acquisition process.

Figure 2 shows a design process flowchart for the prototype of temperature logging tools. This prototype tested the prototype in a hot spring in the geothermal prospect area in Gunung Pancar, Bogor.

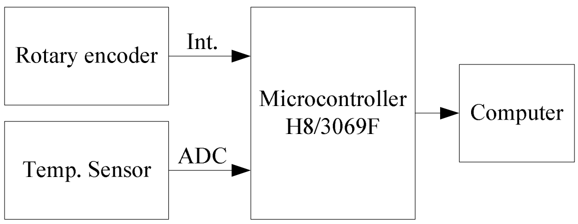

Figure 1. Intrumentation System of Temperature Logging Tools

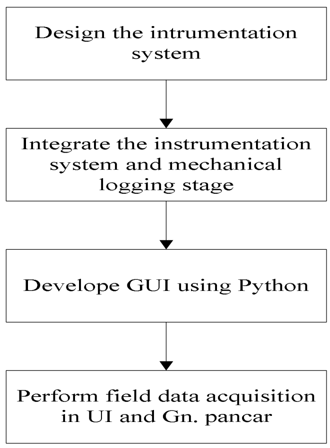

Figure 2. Design Process Flowchart

has been tested in one borehole having a 25 m vertical depth at the University of Indonesia. We have also Gunung Pancar which is located in Karang Tengah village, Bogor, West Java. It is about 70 km southwest of Jakarta. The altitudes of the prospecting area where surface manifestations exist vary between 300 to 800 m above sea level. The existence of hydrothermal activities have been observed locally in the Kawah Merah hot spring, which has a surface water temperature of 65.1 °C.

3. Results and Discussion

The Pt-100 temperature sensor needs to be calibrated with a thermometer. We immersed the sensor and thermometer into 26 ^{o}C water. Then, the water was heated gradually so that its temperature increased slowly. The increasing water temperature caused increasing Pt-100 resistance. A voltage divider circuit is used to convert resistance changes into voltage variation. Because ADC input needs a voltage range between 0 to 5 V, the output of the Pt-100 voltage divider needs to be amplified by LM 324. Figure 3 shows a signal conditioning which consists of a voltage divider circuit and an LM 324 amplifier.

Figure 4 shows the result of the Pt-100 temperature sensor calibration, in terms of the linear response of amplified voltage toward temperature changes. The sensitivity of the signal conditioning is about 9 mV for every 1 ^{o}C.

A rotary encoder is an electro-mechanical device that converts the angular position or motion of a shaft into a digital pulse. In this design, the linear displacement of temperature along the borehole is converted into rotational motion. The digital pulse output of the rotary encoder is sent to the H8/3069F microcontroller using an interrupt (IRQ) connection.

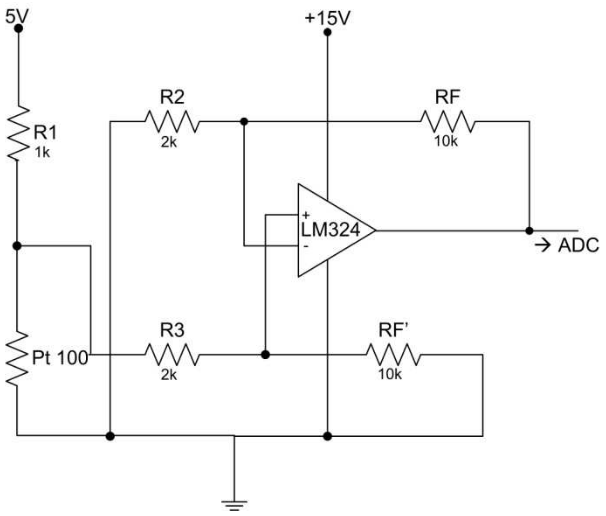

Figure 3. Signal Conditioning Circuit for Pt-100 Temperature Sensor

There is a voltage difference between the digital pulse of the rotary encoder and the digital input of the microcontroller. The high voltage of the digital pulse of the rotary encoder is 10V, while the maximum digital input of the microcontreller is 5V. So we designed a voltage converter circuit using an optocoupler 4N28, as shown in Figure 5.

We measured the linearity of the linear displacement and the pulse counting from the rotary encoder. It is clearly shown in Figure 6 that the linear displacement has a linear relation with pulse counting. The rotary encoder used in this design emits 1000 pulses per rotation with an error approximation of 0.011%. It means that after the temperature sensor moves down to 100 m, there will be an error of around 1 m.

As an interface between the user and the temperature logging system, we have developed a GUI using Python programmning language. The GUI (Figure 8) visualizes collected temperature data during measurement in real time. The GUI has two main parts, i.e. a control panel

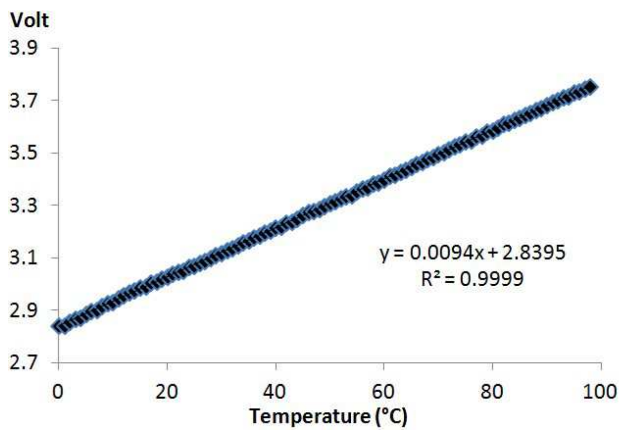

Figure 4. Calibrated Curve of Pt-100 Output After Amplification by LM324

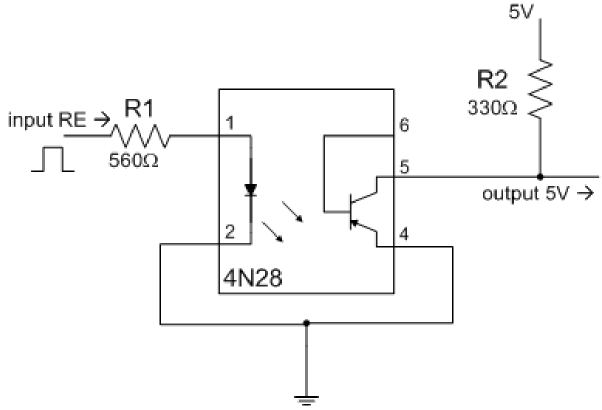

Figure 5. Voltage Converter Circuit for Rotary Encoder

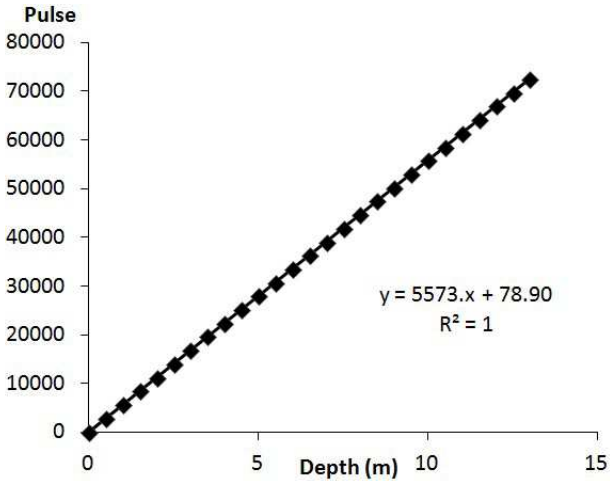

Figure 6. Linear Displacement for Measuring Depth in Meter Versus Pulse Counting

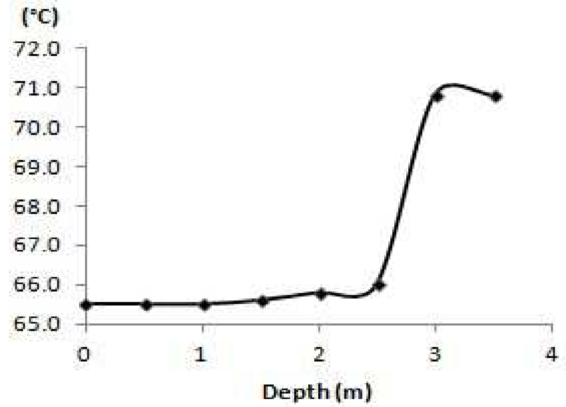

Figure 7. Temperature-depth Variation in Kawah Merah Hot Spring, Gunung Pancar, Bogor

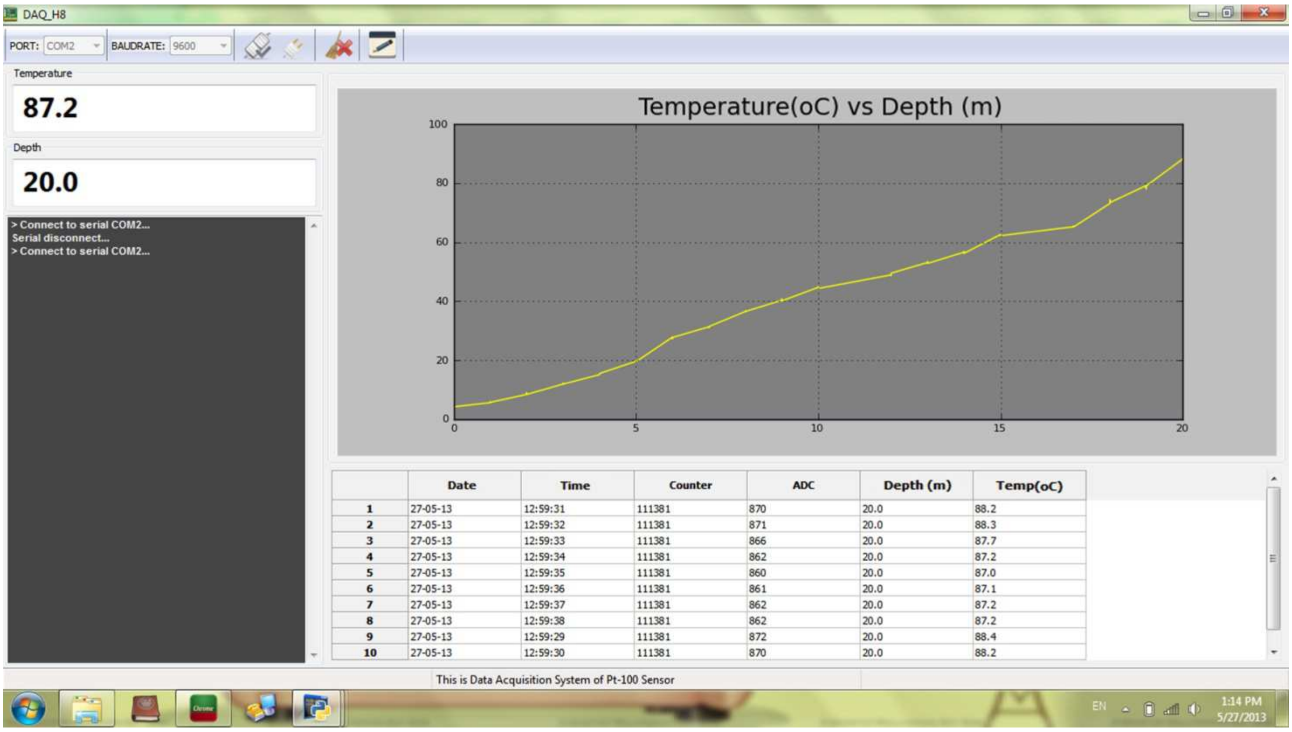

Figure 8. The Graphical User Interface of Temperature Logging Tools

on the left side and a graphic on the right side. The control panel consists of several buttons, including a Connect button that is functioned to start the data collecting process. The Disconnect button will stop the data collecting process. The GUI has the ability to display previous data acquired by means of the Open File button. The measured temperature can be read on a window above the Connect button. We also put an ADC reading just to make sure of the value or number of the measured temperature.

On the right side of the GUI, we display data acquired as a graphic. The yellow line indicates the ADC reading, while the blue line indicates the measured temperature variation in a borehole.

The complete system of temperature logging tools is shown in Figure 9. The prototype has been used to measured subsurface temperatures along a borehole which is located next to the Department of Physics at the University of Indonesia. This location has no geother-

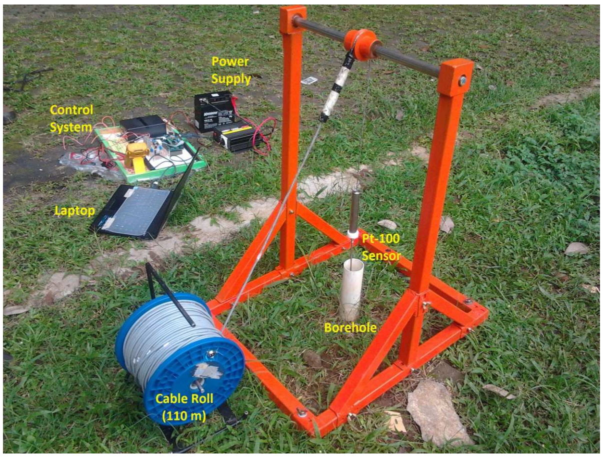

Figure 9. The Prototype of Temperature Logging Tools

mal manifestation, so that we have not found a thermal gradient.

To measured temperature variations in geothermal prospect areas, we performed data acquisition at the Kawah Merah hot spring located in Gunung Pancar, Bogor. The hot spring has a surface temperature of about 65.5 °C. The measuring was started from the water surface by immersing the sensor in the water. Then, the sensor was moved down gradually in 50 cm intervals while the temperature was measured. Unfortunately, because of substantial sediment accumulation inside the hot spring, the maximum depth of measurement was no more than 4 m. The temperature at the maximum depth was 70.8 °C (Figure 7). Based on the measurement data, we have estimated the thermal gradient to be around 1.5^{o}C/m. It means that the thermal source may be located at a certain depth below the hot spring.

4. Conclusions

The prototype of thermometer logging tools has already been designed. The calibration results of the rotary encoder show an error reading of around 0.011%. It means that after the temperature sensor moves down to 100 m, there will be an error of around 1 m. The sensitivity of this prototype is 9 mV/^{o}C. It means that the system can detect temperature changes of about 1 ^{o}C by a voltage difference of about 9 mV. The first utilization of the prototype has already been done in the Kawah Merah hot spring. The thermal gradient below the hot spring has been estimated at around 1.5 ^{o}C/m.

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