Development of the Smart Transformer Detection Learning Kit Using IoT

Chanudon Chueapram, Kanyama Kamata, Tanapoom Rueangphaisan, Yuwarat Srisupawong, and Noritsugu Kamata

***Abstract*—The Internet of Things (IoT) concept is one of the most popular concepts that can be applied from simple things to the smart appliances of today. IoT also helps human life to be more convenient and easier. IoT for learning and teaching in higher education is so important to help students gain their knowledge and experience before graduation and industrial work. An Introduction of IoT course for undergraduate students mostly focuses on the IoT concepts and fundamentals which may affect learners to understand well about the concepts. To apply those concepts into practice is still quite difficult for learners. This article proposes the development of a learning kit for the Smart Transformer Detection System using IoT as teaching material. The capability of this tool can help learners automatically detect and notify events using online tools. Moreover, it helps students monitor the transformer system with IoT concepts more clearly, practically, and understandingly. The study volunteered a sample group of students who used this kit in their learning and practices. Then, the sample did a survey on learning satisfaction. The results show that students were very satisfied with both accuracy of the work system and the quality of the learning kit.**

***Index Terms*—Internet of things (IoT), learning kit, transformer, undergraduate students.**

I. Introduction

Nowadays, the Internet of Things (IoT) is a concept that plays an important role in daily life. Not only in everyday use but also in many professional domains such as farming, healthcare system, engineering, learning and teaching, etc. IoT becomes the idea to create values in their professions that differ from others. To design equipment and electronic devices with IoT features requires a variety of knowledge and experiences. It is important to develop IoT devices that meet user needs including physical appearance, device features, device specifications, reporting function, compatibility with users, ease of use, etc.

For the teaching and learning domains, IoT is also taking an effect on teaching material. The second-year electrical engineering students are required to complete "Introduction of Internet of Things" course. The course required lecturers to teach and help students understand the IoT concepts, the characteristics of IoT, and the different types of devices related to IoT. However, students seem to have enough fundamental knowledge and understand IoT concepts so well. When a lecturer asked students how to apply their knowledge to practice. Everything seems to be stuck and silent in class. It may imply that they still lack practicing skills including installation, IoT programming, hardware, software, and connecting device skills.

The study chose the transformer concept to be the content of the learning kit because this concept is one of the most important parts of "Power Plant, Transmission and Distribution System" course for electrical engineering students. The transformer is a crucial component of the electric power transmission system. The movement of electric energy from the generating station and distribution to customers relates to the transformer. The transformer helps the system increase voltage from the power plants to transmit with long-distance or decrease voltage at the end station before supplying to homes. For a better understanding of how the transformer detection system works, IoT provides many beneficial features to work with simple electronic devices such as the transformer. IoT can help the system interact with learners, it also reports, detects, and sends out any notification to students. An effective teaching aid related to students' learning content is very important to engage students to learn and understand their topic. The lack of teaching aid may influence students' understanding level and discourage their learning [1].

Thus, the study included both the transformer and IoT concepts in the learning kit. It mainly focused on the development of IoT functions for the transformer detection system. Students have chances to experiment by themselves, monitor the system, understand the development and functions of the learning kit, understand new technology usage, and perceive the way to apply concepts to practical activities. For example, learners can observe, touch, try on, and do experiments with sensors, a microcontroller board, IoT programming, installation method, and online reporting tools. The parameter usage of the transformer consists of the level of voltage, the current on both the input and output sides of the transformer, and the efficiency of oil inside the transformer such as the dielectric strength, oil temperature, and oil level to measure the transformer efficacy [2]. The obtained data from various parameters can be used to analyze data in various conditions to find causes of the problems or malfunctions, forecasting events in near future, etc. [3]. Then, the survey of students' satisfaction with the learning kit was delivered to investigate students' perceptions of the kit in the aspects of the accuracy of the transformer detection system and the quality of the learning kit.

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II. Concept and Approach

The Internet of Things (IoT) is a very popular idea in the real world today. IoT is the concept of connecting between the physical world and the digital world [4] using sensors and connected devices. People can perceive changes in many physical things which come from human-made such as light intensity controlling via an online application [5], smart farming [6], an automatic dog feeder, etc. The study adopted the idea of IoT to change from a hardware transformer to a smart device that can monitor, detect, and report via applications e.g., Thingspeak, and Line. In addition, the data collected from this device can be accumulated to predict and tell what things may occur in the future [7]. The idea of IoT devices can help a lot of learning and teaching in higher education. Developing the IoT learning kit for electrical engineering students seems to be very beneficial for their learning and practice. Before IoT, students learned to know hardware from programming using machine language to control the hardware. It is not easy to adapt, apply, and report to a visualized tool as nowadays IoT. This technology bridges a gap between old technology and new technology together and makes difficult things easier. Students have a big chance to gain more knowledge, experience, and technical practice from this learning tool.

The study brought the concept of IoT to connect between the physical world and the virtual world using the Internet network. When students experiment with the learning kit, learners will know how to connect each part of the equipment or devices. Students will see how to use and observe the various sensors to detect the physical changes of the transformer such as changes in oil temperature, transformer input and output voltage, and oil level. In addition, students will gain knowledge from observing how to use the microcontroller board to connect sensors to the Cloud, and how to write computer programing to control the transformer detection system connecting with IoT. For the user interface (Virtual World), Thingspeak will use for data visualization such as graphs and dashboards, and Line Notify will use to send notifications to users. In the design, we will use very simple equipment which is a reasonable cost and easy to find in the market such as basic sensors, the simplest Microcontroller board with the least complexity for connecting, and online platforms with ease of use. These may let students easily engage in their learning and they may gain a better understanding of practical learning activities of the transformer and IoT concepts from the learning kit [8].

Fig. 1 is the IoT conceptual diagram for data collection, data transferring, data analysis, and data presentation.

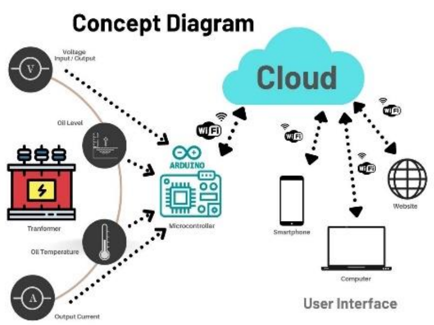

Fig. 1. IoT conceptual diagram.

III. Hardware Design

A. The Transformer Maintenance Monitor Design

A transformer is an electrical device that is constantly in use. As a result, the transformer has easily deteriorated. Factors that cause transformer deterioration are winding temperature, oil temperature, ambient temperature, load current, oil flow (motor pump), humidity and dissolved gas, LTC, oil level monitoring, buoy condition, overload, oil, temperature, load current, and ineffective cooling of the transformer [9]. In this research, a model will be used to test the recording of voltage, current, oil level, and oil temperature as shown in Fig. 2. By collecting the values from the model, various sensors are used to connect the microcontroller board to send the values to the Cloud using IoT features as shown in Fig. 3.

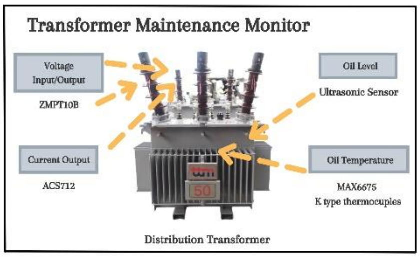

Fig. 2. The design of transformer maintenance monitor.

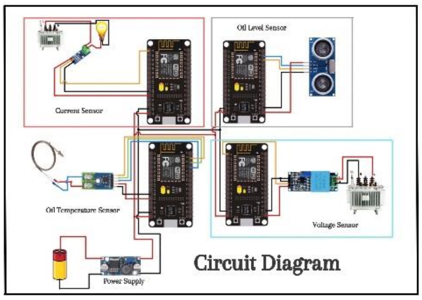

Fig. 3. Circuit diagram.

B. The Transformer Model

The model uses a transparent poly (methyl methacrylate) material with a thickness of 5 mm., which is designed to resemble the shape of a transformer. It has a rectangular shape with dimensions of 150×300×150 mm. The inside of the model is divided into 2 compartments with dimensions of 150×150 mm. for inserting a simulated transformer. The model can also fill up oil thus the design of it should be careful of the leak. The cover will use the same material as the base with a size of 150×300×20 mm. as shown in Fig. 4 and Fig. 5

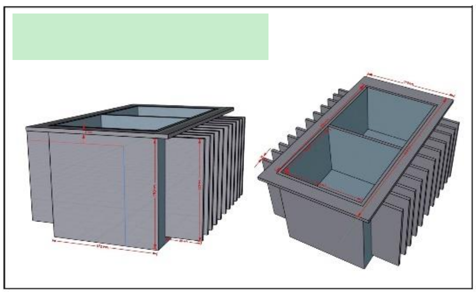

Fig. 4. The 3D transformer model.

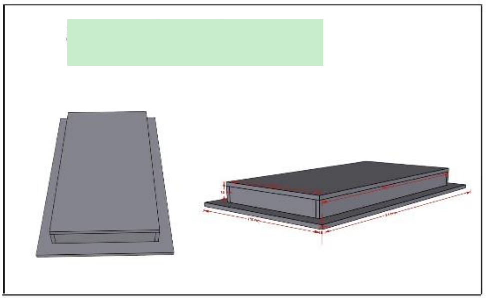

Fig. 5. The 3D transformer model.

C. The Voltage Measurement Using ZMPT10B

Sensor ZMPT10B is a sensor for measuring AC voltage in the range of 0-250V. The sensor has a power supply ranging from 5 to 30. It will read the value and send it back with an analog signal to use on the microcontroller board. It should not be used near the magnetic field because of the Hall Effect [8]. To use it, there will be a value for all 4 pins as follows: Pin VCC and GND for powering the board, and output pins for sending an analog signal to the microcontroller board.

D. The Current Measurement Using ACS712

To measure the operating current of the transformer, a Hall Effect ASC712 [10] sensor is used to measure the current as shown in Fig. 6. The measurement is based on the principle of measuring the magnetic inductance that varies with the current. The output is a voltage and can be used to connect to the analog read pin of the Arduino. ACS712 sensor consists of a Hall Effect linear output circuit. There is a copper inductor circuit located around the surface of the ACS712 chip. When an AC or DC current passes through the copper wires, a magnetic field is generated. This electromagnetic field interacts with the Hall Effect sensor and converts it. It is a voltage proportional to the current, either AC or DC depending on the type of input current.

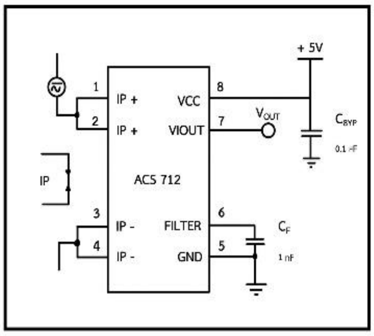

Fig. 6. ACS712 structure.

E. To Measure the Oil Level Using An Ultrasonic Sensor

The design relies on the reflection of sound waves to determine the level of oil. The working principle of an ultrasonic sensor is to send sound waves in an ultrasonic region to strike an object or workpiece detected and then reflect the sound waves to the sensor [11]. It can be possible to check the detection distance in the design. An ultrasonic sensor is installed at the top of the interior parts that use oil. To send out sound frequencies to hit the surface of the oil and reflect the sensor are shown in Fig. 7. As a result, this brings to know the maximum level of oil contained within the parts of the transformer.

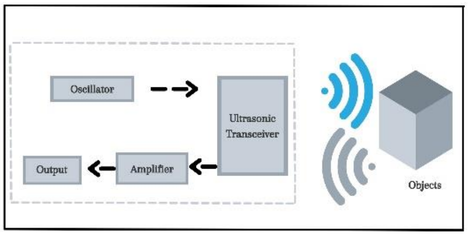

Fig. 7. Working principle for ultrasonic sensor.

F. The Design of Sensors for Measuring Oil Temperature with K Type Thermocouple Temperature Sensor with Digital Converter Module

A thermocouple is a device for measuring temperature using the principle of changing temperature or heat into electromotive force (EMF). A thermocouple is made of two different conductors as shown in Fig. 8 (they differ in atomic structure). To bring the two ends to connect together at one end is called the temperature measurement point. The other end is called the reference point. If the temperature measurement point and the reference point are different, current conduction is in a thermocouple circuit on both sides.

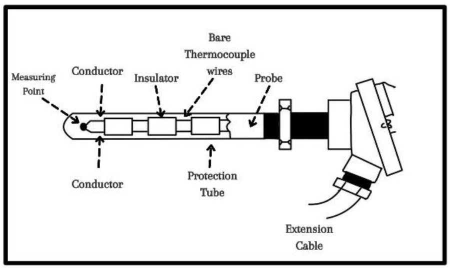

Fig. 8. K-type thermocouple model.

IV. ESP8266 Microcontroller

ESP 8266 board is the most popular board for microcontrollers for IoT today because of its simple operation and reasonable price [12]. It comes with a Wi-Fi feature with full TCP/IP connectivity. This board supports voltage 2.5 ~ 3.6V, system interface: UART /SDIO /SPI /I2C /I2S /GPIO /ADC /PWM., various operating systems, AT instruction set, Cloud server, and Android/iOS. It communicates with each other on Protocols 802.11 b/g/n (HT20) There is 16 GPIO pins [13], [14] as shown in Fig. 9

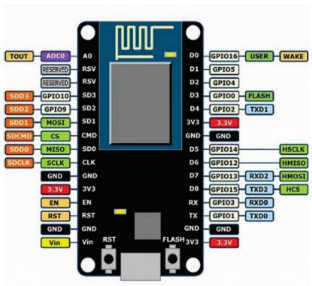

Fig. 9. ESP 8266 module [15].

V. Software Design

A. Code for Voltage Measurement

First, run the “Filters” library for calculating the output voltage. Second, declare the variables uses to determine the frequency and length of the signal range. One variable is used to define the input from the sensor at channel A0. Two variables used for calibration sensors are intercept and slope. Third, declare the current volts variable. Fourth, call the functions from the library runningStatistics, inputStats, and inputStats.setWindowSecs (windowLength) using a while loop. Fifth, declare a variable sensor = analogRead (A0) and call the function.inputStats.input (sensor). Last, check the condition if true computed in a formula of the library, and then generate outputs as voltage.

B. Code for Current Measurement

First, run the library ACS712.h. Then, declare a variable to get the current sensor (ACS712) at column A0. In a void setup, call the variables used for setting 0 and calibrate the current sensor (ACS712). In a void loop, declare the value
I = sensor.getCurrentAC (The resulting value will be a ready-made value that the library has successfully converted).

C. Code for Oil Level Measurement

First, declare pins echoPin = 5 and trigPin = 4, and declare two types of variables: duration (used to store variables derived from sensors) and distance1 (variables used to store values already computed from the formula). In a void setup, set the mode of the pin. TrigPin is output and echoPin is input. In a void loop, use digitalWrite to set TrigPin to signal LOW for 2 microseconds, instruct TrigPin to be signal HIGH for 10 microseconds, and instruct TrigPin as TrigPin to signal LOW again. Then, store the value obtained from echoPin into variable duration. After that, enter the value stored in duration into the equation 1. After the calculation is done, the periodic value of the oil is obtained in millimeters.

$$Duration = 170 - ((duration \times \frac{0.034}{2}) \times 10 \qquad (1)$$

D. Code for Oil Temperature Measurement

First, run library max6675.h. Then, define all 3 signal pins: 1. Pin D0 = 5, 2. pin CS = 4, and 3. pin CLK = 0. After that, call the command from the 6675 thermocouples library (thermoCLK, thermoCS, thermoDO). In a void loop, call a function from the thermocouple library. readCelsius

E. Code for Connecting with Thingspeak

To connect the Thinkspeak platform to display values from the sensor, a channel must be created in Thinkspeak. When a channel is created, a channel ID and API Keys are assigned to the connection. The connection must bring both values to declare in the code of Arduino IDE program for the board to send data. In a void loop, variable X is set to be equal to ThingSpeak. writeField (myChannelNumber, 1, Value, myWriteAPIKey) is used to assign to a given channel and field.

F. Code for Connecting with Line Notification

To write the code to notify users via the Line application. The library (TridentTD_LineNotify.h) will be called. After that, a Line token must be set to define the destination of sending data. In a void loop, there are configurations used to transmit data such as If the oil level is below than the set level, a notification will be sent to users.

VI. USER INTERFACES

A. Thingspeak

Cloud is a platform that uses to store and accesses data via the internet in real-time. In this experiment, we use the Cloud services of Thingspeak to store and upload IoT data to the Cloud. We can also perform analysis, visualize, or aggregate data in real-time [16]. In Thingspeak, we have to create a channel having different fields to store and represent data coming from different sensors through the internet. We create 5 fields to connect with the following five sensors: input and output voltage measurements, current measurement, oil level measurement, and the temperature of the oil as shown in Fig. 10

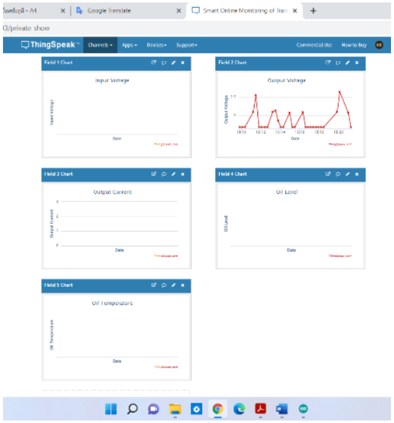

Fig. 10. Fields in Thingspeak.

B. Line Notification

In terms of connecting the system with users, we have chosen to use Line to notify users because LINE is so popular and can support many operating systems. The service is HTTP POST. The access token is applied as a code when using LINE API. TridentTD_LineNotify library is available for ESP8266 and ESP32 which can send with text, stickers, and images with URL [17]. For this experiment, a real-time simulated notification was sent to the user's chat that the transformer fault as shown in Fig. 11

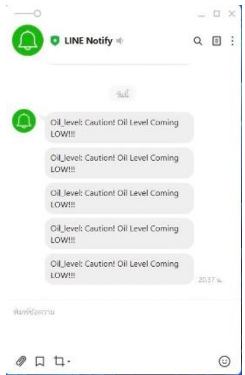

Fig. 11. Examples of line notification to users.

VII. RESULTS

A. Testing of Measuring Voltage Sensor

To test the accuracy of the voltage readings, we compared the SANWA CD 770 voltmeter with the ZMPT10B sensor connected to the Mega 2560 microcontroller board. We read the value through a serial monitor which is measured by equation 2. The result shows sensor error values in the range of 0 - 0.052% as shown in Table I

$$\%EROR = \left|\frac{X_m - X_t}{X_t}\right| \times 100 \quad (2)$$

TABLE I: MEASURING VOLTAGE SENSOR

Meter	1st	2nd	3rd	Avg.	% Error
229.4	228.85	229.95	229.23	229.34	0.02
50.30	50.47	50.52	50.48	50.49	0.37
25.36	25.40	25.27	25.26	25.31	0.19

B. Testing of Measuring Current Sensor

To test the accuracy of the current reading, the test is done by using ACS712 sensor connected with the Mega 2560 microcontroller board. The value is read through a serial monitor of the load with different power ratings. To test at a voltage of 230 volts, Equation 3 will get the values of the current of each load. The calculated values are compared with the sensor reading to determine the sensor error as shown in Table II

$$P = \frac{V}{I}$$

$$I_{Test} = \frac{P_{Load}}{V_{Test}} \quad (3)$$

TABLE II: MEASURING CURRENT SENSOR

Current Load	1st	2nd	3rd	Avg.	% Error
0.17	0.18	0.20	0.18	0.19	11.7
1.00	1.05	1.05	1.05	1.05	5
3.56	3.60	3.60	3.57	3.59	0.84

C. Testing of Measuring Oil Level Sensor

An ultrasonic sensor is used to test the accuracy of the oil level. The sensor is connected to the Mega 2560 microcontroller board and the value of the oil level is read through a serial monitor. The value of the oil level can be adjusted. The comparison is based on the oil level reading with Vernier calipers. This can help to measure the movement of the oil level reading using equation 2 as shown in Table III.

TABLE III: MEASURING OIL LEVEL SENSOR

Vernier Calipers	1st	2nd	3rd	Avg.	% Error
30	30.09	30.09	29.07	29.75	0.83
50	50.83	49.98	51.00	50.60	1.2
60	60.01	59.84	59.84	59.89	0.18
70	70.55	70.55	69.53	70.21	0.3
80	80.24	79.05	79.22	79.50	0.62

D. Testing of Measuring Oil Temperature Sensor

To measure the accuracy of oil level reading using an ultrasonic sensor, the reading is compared with Vernier Calipers. The level of the oil is adjusted, and Vernier Caliper is read as a reference. After that, an ultrasonic sensor is used to connect to the Arduino Mega 2560 board, read the value through the serial monitor, and find the error value of the reference reading by Vernier Caliper as shown in Table IV.

TABLE IV: MEASURING OIL TEMPERATURE SENSOR

Thermo meter	1st	2nd	3rd	Avg.	% Error
22	21.95	21.50	21.73	21.73	1.22

E. Students' Learning Kit Satisfaction

To measure the effectiveness of the learning kit, a survey was conducted to assess students' satisfaction. The samples were seventy-six students of the Department of Electrical Education at King Mongkut's University of Technology Thonburi. They had a chance to use and try on this kit in their IoT learning course before doing a survey. A survey of students' satisfaction is composed of 4 items of the learning kit working with accuracy, and 6 items of the learning kit quality. The students' learning kit satisfaction with each item shows in Fig. 12.

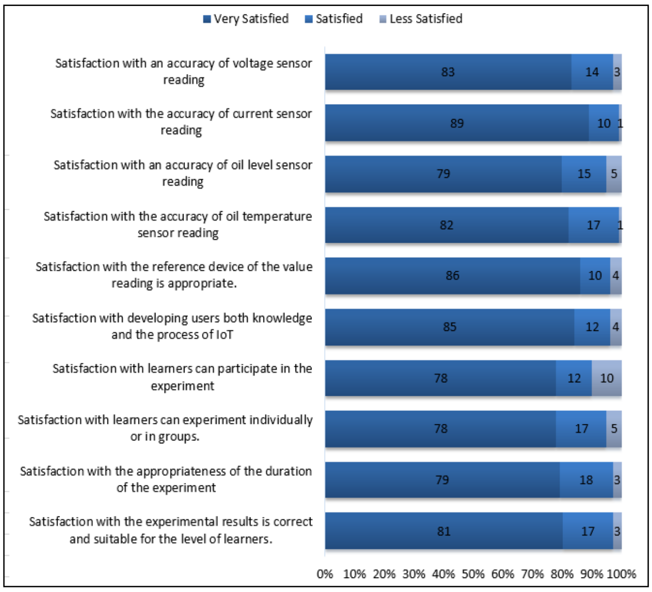

Fig. 12. Students' satisfaction.

F. The Results of Students' Satisfaction with the Accuracy of the Transformer Detection System

The results show that the item of "Satisfaction with the accuracy of current sensor reading" was rated as very satisfied at 89%, along with "Satisfaction with an accuracy of voltage sensor reading" at 83%, "Satisfaction with the accuracy of oil temperature sensor reading" at 82%, and "Satisfaction with an accuracy of oil level sensor reading" at 79%.

G. The Results of Students' Satisfaction with the Learning Kit Quality

The results show that the "Satisfaction with developing users both knowledge and the process of IoT" item was rated as very satisfied at 85% and less satisfied at 4%.

The "Satisfaction with learners can participate in the experiment" item was rated with the lowest satisfaction level. The scores are very satisfied at 78% and less satisfied at 10%.

VIII. Conclusion

This study aimed to develop the learning kit for the transformer detection system using IoT for undergraduate students to use as a teaching aid in the IoT class. This medium will help learners better understand the concepts of IoT and the transformer detection system including factors affecting the transformer's efficiency. In the design of the detection system, sensors are used to measure factors causing the transformer to malfunction. There are 4 recording data: voltage level, current level, oil level, and oil temperature. The system will send any notification to Cloud and online tools such as Thingspeak and Line. The testing results from all sensors by comparing the sensor readings from the serial monitor program with the readings from measuring instruments showed that the error was at a low level. In addition, the results of the survey revealed that learners were very satisfied with the learning kit in terms of the accuracy of the system and the quality of the learning kit. However, this study is a limitation of the learning kit which can record only 4 kinds of data. The findings may be beneficial for further media improvement with better function to record more variety of data which help the transformer improve efficacy, performance, and accuracy of its detection.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Chanudon Chueapram, Kanyama Kamata, Tanapoom RueangPhaisan, Yuwarat Srisupawong, and Noritsugu Kamata conducted the paper and did literature review; Chanudon Chueapram approved the final version of the paper.

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