

Teaching Instrumentation to Electrical Engineering Students Using LabJack U12 Data Acquisition Unit

Abraham Dandoussou
Department of Electrical and Power Engineering
University of Buea
Kumba, Cameroon
abraham.dandoussou@ubuea.cm

Pierre Kenfack
Department of Electrical and Power Engineering
University of Buea
Kumba, Cameroon
pierrekenfack2003@yahoo.fr

Abstract – LabJack U12 is among the various USB data acquisition units widely used today. The device uses USB cable to be connected to a personal computer, which is also used for its power supply. With its various screw terminals, its implementation is made easy in many applications. LabVIEW software is necessary for data acquisition process. The main objective of this paper is to help electrical engineering students to implement some temperature sensors using LabJack U12. Among those sensors, there are: a resistive temperature detector (RTD), a negative temperature coefficient (NTC) thermistor and a type K thermocouple. The obtained results make students to be familiar with the use of LabJack U12 and LabVIEW software. This will help them in their various professional projects.

Keywords- USB Cable, Data Acquisition, Temperature sensor, LabVIEW

I. INTRODUCTION

Today, many electronics equipment are using the Universal Serial Bus (USB) because of the easy connection. New technology of portable data acquisition units is based on USB connectivity which allows high data rate [1-3]. Many companies like LabJack, Measurement Computing Corporation and National Instruments manufacture various types of data acquisition units available in the markets [4; 5]. LabJack U12 data acquisition unit has an USB connectivity that allows it to be used in various engineering applications, especially laboratory practice for engineering students. It has many features that include analog voltage input and output channels, digital input/output, counter, +5 V DC supply, etc. The implementation of LabJack U12 is made easy via LabVIEW software or many other software. All necessary wiring is done on the hardware unit of LabJack U12. The device is connected to a personal computer (PC) through an USB cable. The software is run to provide all application possibilities [6]. With a relatively low cost, USB data acquisition units can easily be purchased for home use, industrial use, teaching use, etc. Various sensors can be connected to the data acquisition units. This will help to monitor a process by visualizing the measured parameters on the PC. This paper presents implementation of LabJack U12 using LabVIEW software. The main objective is

to help engineering students to be familiar with hardware and software for instrumentation systems. Students should know how to interface sensors to a data acquisition unit and how to use a software to display and to record measured signals. Sensors are electronic devices that convert any physical signal into an electrical signal (current or voltage). Among sensors, there are temperature sensors that are always studied in instrumentation courses. Temperature sensors convert temperature into a voltage. Thermocouples, resistive temperature detectors (RTD), thermistors are some types of temperature sensors. The easiest way of implementing those sensors is to interface them to a data acquisition unit like a LabJack U12 data acquisition unit. Data acquisition is very important in process control [5-7]. In this paper, some applications in temperature control have been implemented.

II. HARDWARE AND SOFTWARE PRESENTATION

A. Hardware Presentation: LABJACK U12

The data acquisition device LabJack U12 is among those new data acquisition devices widely used. Figure 1 shows the top view of the device. LabJack U12 has four external features:

- A USB connector for the connection to the computer through a USB cable provided by the manufacturer. The USB cable is also used for the power supply of the device, no external supply is needed.
- DB25 digital I/O connector which provides sixteen additional digital I/O terminals (D0 – D15).
- Status LED which blinks once the device is connected to the computer and stays on when it is ready to work.
- Thirty screw terminals made up of eight analogue inputs (AI0 – AI7), two analogue outputs (AO0 and AO1), four digital I/O (IO0 – IO3), one counter terminal (CNT), two factory primarily used terminals (CAL and STB) for Calibration and Testing, four +5 V terminals (voltage produced by the device

when connected to the computer), and nine ground terminals (GND).



Figure 1 – Top view of LabJack U12

B. Software Presentation: LABVIEW 2019

LabVIEW software is used as GUI for the implementation of data acquisition devices. The software is easy to install on a computer after purchase. Additional drivers are needed for the implementation of LabJack U12. After successful installation of LabVIEW, the user has to download a zipped folder of LabJack U12 named “LabVIEW## LJU12”. This folder has many sub-folders after being unzipped. The sub-folder named “LabJack” must be copied and pasted in the \vi.lib\addons\ folder of LabVIEW directory. This will allow the LabVIEW Function Palette to have LabJack’s functions. LabVIEW is essentially used for virtual instruments (VIs). For this work, LabVIEW 2019 has been used to design the various VIs of the applications [7].

III. SOME PRACTICAL APPLICATIONS

A. Resistive Temperature Detector

A resistive temperature detector (RTD) is made up of a material which resistance changes when the ambient temperature (or surrounding) changes. The material is characterized by its temperature coefficient denoted by α (given in K⁻¹ or °C⁻¹). At the reference temperature (T_0), the material has a resistance denoted by R_{T_0} . The relationship between the ambient temperature (T) and the resistance of the material (R_T) is given by equation (1) [8; 9].

$$T = T_0 + \frac{1}{\alpha} \left(\frac{R_T}{R_{T_0}} - 1 \right) \quad (1)$$

As the temperature is converted into a resistance by the RTD, it is necessary to use an adequate converter circuit in order to convert the resistance (R_T) into a voltage. There are various types of circuits that can be used: a potentiometer circuit, a Wheastone Bridge circuit, etc. For this laboratory practice, a potentiometer circuit has been used, as shown in figure 2. The voltage drop across the resistor R_1 and the output (or the measured) voltage are given by equation (2), when assuming an open output.

$$V_{R_1} = R_1 I \quad \text{and} \quad V_{out} = R_T I \quad (2)$$

The potentiometer circuit can be wired to the LabJack data acquisition unit as shown in figure 3. Here, the voltage drop across the resistor R_1 is measured as a differential voltage between ports AI0 and AI1 of the LabJack unit. It is represented on the

LabVIEW model (see figure 4) as an input denoted by V_r . The measured voltage across the RTD is obtained between ports AI2 and AI3, and denoted by V_{rtd} . It should be noted that using equation (2),:

- Voltage V_r read by the LabJack unit is used to determine the current in the circuit as shown in equation (3).

$$I = V_r / R_1, \text{ with } R_1 = 10 \text{ k}\Omega \quad (3)$$

- Voltage V_{rtd} read by the LabJack unit is used to determine the resistance of the RTD as shown in equation (4).

$$R_T = V_{rtd} / I \quad (4)$$

- The temperature measured by the RTD is calculated from equation (1), in degrees Celsius (°C). Its value in degrees Fahrenheit (°F) is given by equation (5).

$$T (^\circ F) = T (^\circ C) \times \frac{9}{5} + 32 \quad (5)$$

The RTD used in this work is a Pt100 having the following characteristics: $\alpha = 0.00385$; $T_0 = 0$ °C and $R_0 = 100$ Ω . The wiring circuit for the implementation is shown in figure 4.

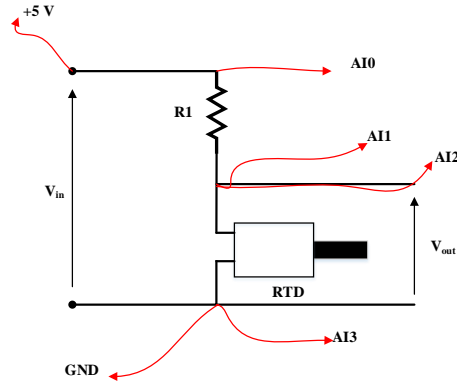


Figure 2. An RTD in a potentiometer circuit

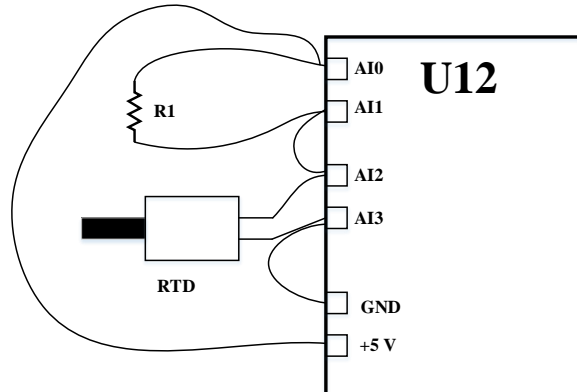


Figure 3. LabJack Wiring Diagram for an RTD

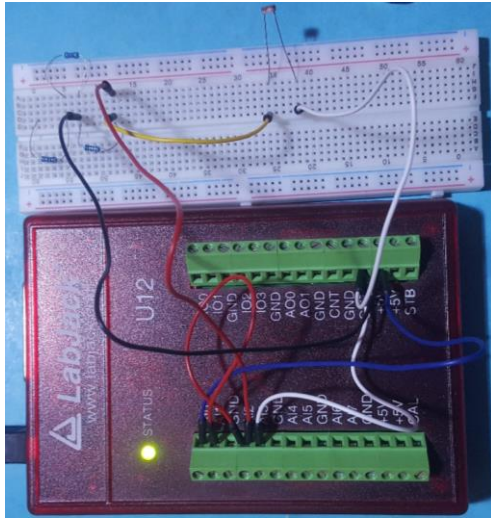


Figure 4. Wiring image of the RTD to LabJack U12

For the LabVIEW model as shown in figure 5, students should follow the following steps:

- Step 1: After running LabVIEW 2019, click on **Create Project**, then **Blank VI**. Two windows will be opened: the Block Diagram window and the Front Panel window. Both of them will be used simultaneously.
- Step 2: Right in the Block Diagram window, then put the cursor on **Structures** in Programming Function. Then click on **While Loop** to draw the while loop rectangle for continuous running. Right click on the red button and select **Create Control** to add a Stop control button.
- Step 3: Add a sample time to the while loop. Right click, then put the cursor on **Timing** and select **Wait (ms)**. Right click on the block and select **Create Constant**. Put the value of the sample time (in milliseconds).
- Step 4: Right click in the while loop, then put the cursor on **Structures** and select **Formula Node**. Draw the formula node rectangle inside the while loop.
- Step 5: Right click on the left side of the formula node rectangle to add inputs. For this experiment, there are six inputs to add: V_r , V_{rtd} , A (alpha), T_0 , R_{T0} and R (which represents resistor R_1 figure 2).
- Step 6: Right click on the right side of the formula node rectangle to add outputs. For our case, there are four outputs to add: R_T , I , T_C (the temperature in $^{\circ}\text{C}$) and T_F (the temperature in $^{\circ}\text{F}$).
- Step 7: From the Front Panel window, right click, then put the cursor on **Numeric** and select **Numeric Control** to add numeric block to the four input constants: A , T_0 , R_{T0} and R .
- Step 8: From the Block Diagram window, right click outside the formula node rectangle, then put the cursor on **Addons**, then on **LabJack** and select **EAnalogIn.vi**, to add two LabJack analogue input blocks. For input V_r , set the channel of the LabJack block to **0-1 Diff** and the gain to **4(+/- 5 V)**. For input V_{rtd} , set the channel to **2-3 Diff** and the gain to **4(+/- 5V)**.
- Step 9: From the Front Panel window, right click, then put the cursor on **Numeric** and select **Numeric Indicator** to display the value of the RTD resistance R_T and that of the measured temperature T (in $^{\circ}\text{C}$ or in $^{\circ}\text{F}$). For the waveform display of the temperature, right click, then put the cursor on **Graph** and select **Waveform Chart**.
- Step 10: For recording the data to a file (Excel file for example), from the Block Diagram window, right click, then put the cursor on **File I/O** and select **Write Meas File**. The setting window will appear as shown in figure 6. Do necessary configuration and click on **Ok**.

The final and correct model should be like the one shown in figure 5. Click on the Run button to run the acquisition process, with the LabJack unit connected to the USB port of the computer. The displayed results are shown in figure 7. In figure 7 (a), the temperature is displayed in degrees Celsius ($^{\circ}\text{C}$), while in figure 7 (b), it is displayed in degrees Fahrenheit ($^{\circ}$). It is necessary to note that, the fluctuations observed are due to the noise signals in the circuit. That is why, a timing block is added to delay the reading operation in order to obtain a stable display [10].

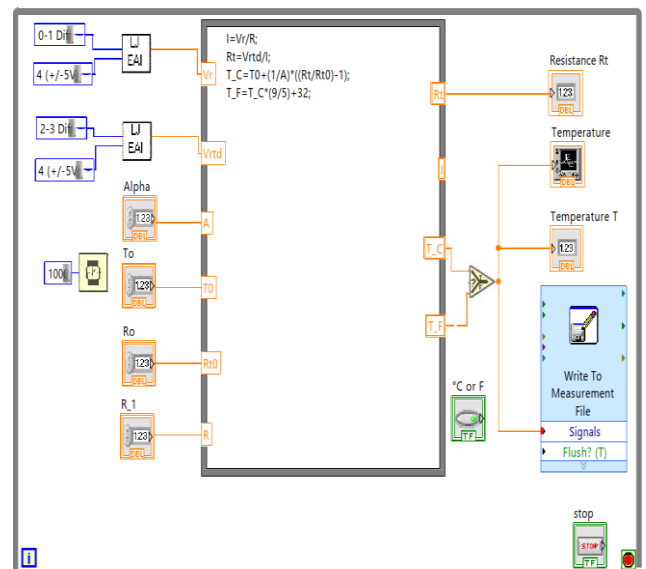


Figure 5. LabVIEW Block Diagram for an RTD

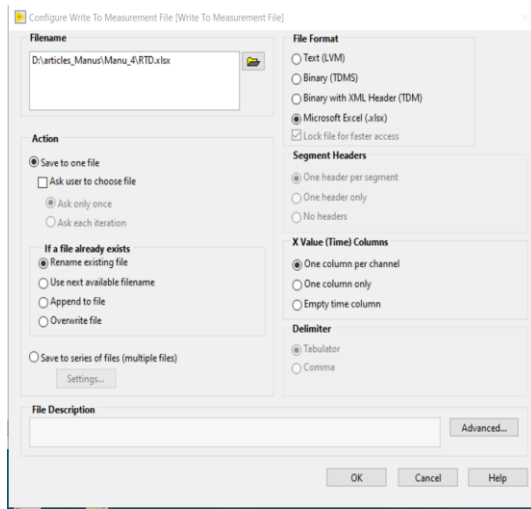
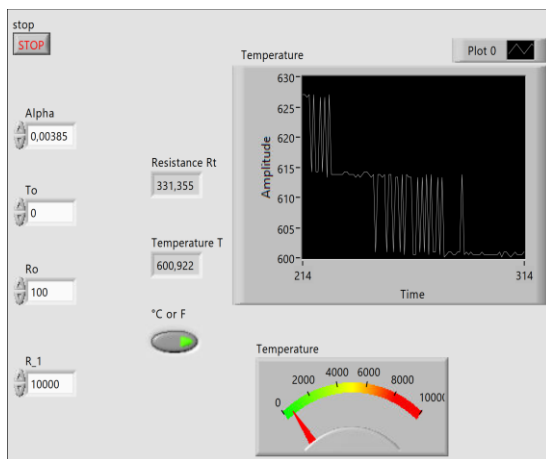
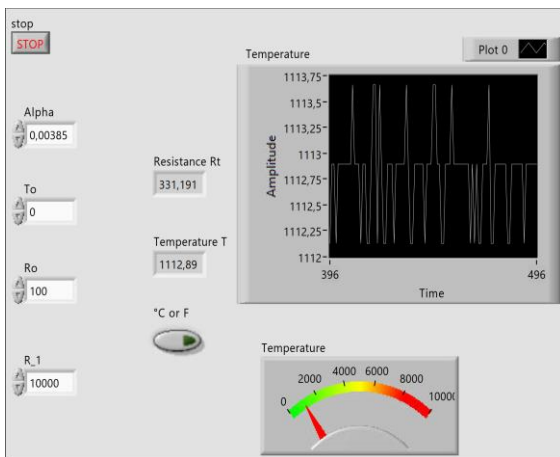


Figure 6. Setting parameters for Data saving for RTD



(a)



(b)

Figure 7. Display results of the temperature measured by the RTD: (a) in °C and (b) in °F

B. Thermistor Temperature Sensor

Like an RTD, a thermistor is made up of a material which resistance varies when the surrounding temperature is changing. The thermistor's material is characterized by its characteristic temperature coefficient denoted by β (given in K). At the reference temperature (T_0), the resistance is denoted by R_{T_0} .

The relationship between the resistance (R_T) and the temperature (T) is given by equation (6) [11].

$$T = \frac{1}{\ln\left(\frac{R_T}{R_{T_0}}\right) \frac{\beta}{T_0} + \frac{1}{T_0}} - 273.15 \quad (6)$$

In order to convert the resistance (R_T) into a voltage, a potentiometer circuit (like in figure 2) is used. The wiring diagram of the thermistor is shown in figure 8 and the wiring image shown in figure 9. For this experiment, the used thermistor is a Negative Temperature Coefficient (NTC) one having as characteristics: $\beta = 3455$; $T_0 = 25^\circ\text{C}$ and $R_{T_0} = 10\text{ k}\Omega$.

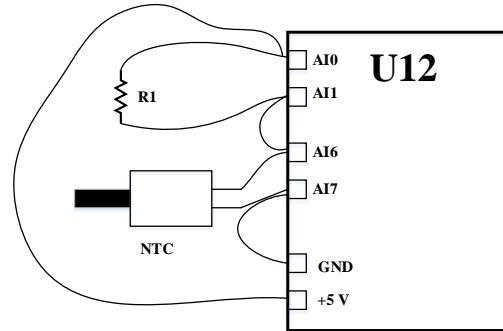


Figure 8. LabJack Wiring Diagram for an NTC

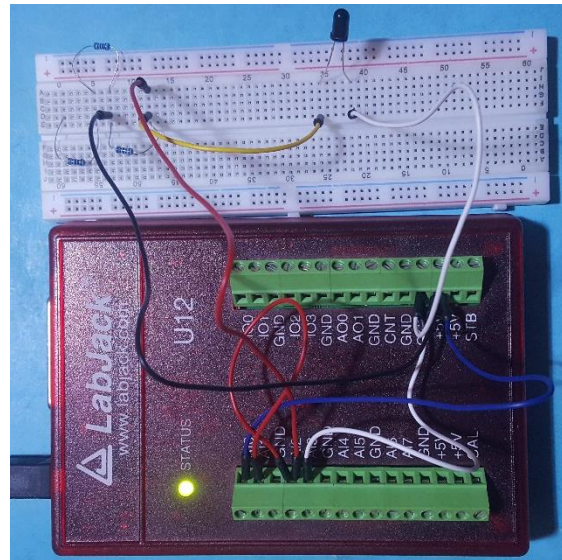


Figure 9. Wiring image of an NTC to LabJack U12

For the LabVIEW model as shown in figure 10, students should follow the following steps:

- Step 1: After running LabVIEW 2019, click on **Create Project**, then **Blank VI**. Two windows will be opened: the Block Diagram window and the Front Panel window. They will be used simultaneously.
- Step 2: Right in the Block Diagram window, then put the cursor on **Structures** in Programming Function. Then click on **While Loop** to draw the while loop rectangle for continuous running. Right click on the red button and select **Create Control** to add a Stop control button.

- Step 3: Add a sample time to the while loop. Right click, then put the cursor on **Timing** and select **Wait (ms)**. Right click on the block and select **Create Constant**. Put the value of the sample time (in milliseconds).
- Step 4: Right click in the while loop, then put the cursor on **Structures** and select **Formula Node**. Draw the formula node rectangle inside the while loop.
- Step 5: Right click on the left side of the formula node rectangle to add inputs. For this second experiment, there are six inputs to be added: V_r , V_{ntc} , B (Beta), T_0 , R_{T0} and R (which represents resistor R_1 in figure 2).
- Step 6: Right click on the right side of the formula node rectangle to add outputs. For our case, there are four outputs to be added: R_T , I , T_C (the temperature in $^{\circ}\text{C}$) and T_F (the temperature in $^{\circ}\text{F}$).
- Step 7: From the Front Panel window, right click, then put the cursor on **Numeric** and select **Numeric Control** to add numeric block to the four input constants: B , T_0 , R_{T0} and R .
- Step 8: From the Block Diagram window, right click outside the formula node rectangle, then put the cursor on **Addons**, then on **LabJack** and select **EAnalogIn.vi**, to add two LabJack analogue input blocks. For input V_r , set the channel of the LabJack block to **0-1 Diff** and the gain to **4(+/- 5 V)**. For input V_{ntc} , set the channel to **6-7 Diff** and the gain to **4(+/- 5V)**.
- Step 9: From the Front Panel window, right click, then put the cursor on **Numeric** and select **Numeric Indicator** to display the value of the thermistor resistance R_T and that of the measured temperature T (in $^{\circ}\text{C}$ or in $^{\circ}\text{F}$). For the waveform display of the temperature, right click, then put the cursor on **Graph** and select **Waveform Chart**.
- Step 10: For recording the data to a file, from the Block Diagram window, right click, then put the cursor on **File I/O** and select **Write Meas File**. The setting window will appear as shown in figure 11. Do necessary configuration and click on **Ok**.

The final and correct model should be like the one shown in figure 10. Click on the **Run** button to run the acquisition process, with the LabJack unit connected to the USB port of the computer. The displayed results are shown in figure 12. The temperature is displayed in degrees Celsius ($^{\circ}\text{C}$) and in degrees Fahrenheit ($^{\circ}\text{F}$) [11].

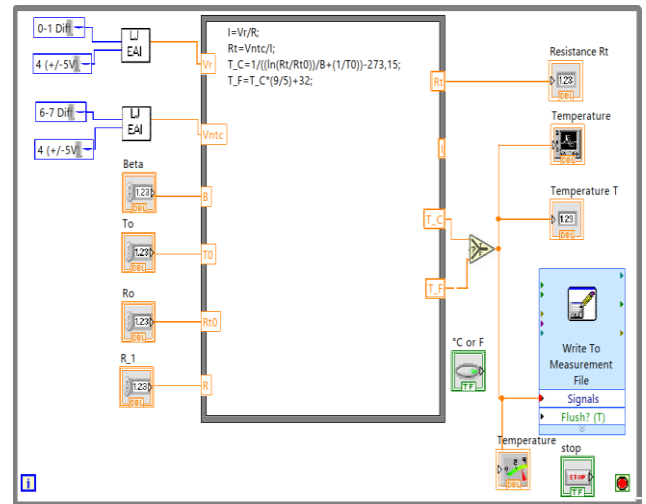


Figure 10. LabVIEW Block Diagram for an NTC Thermistor

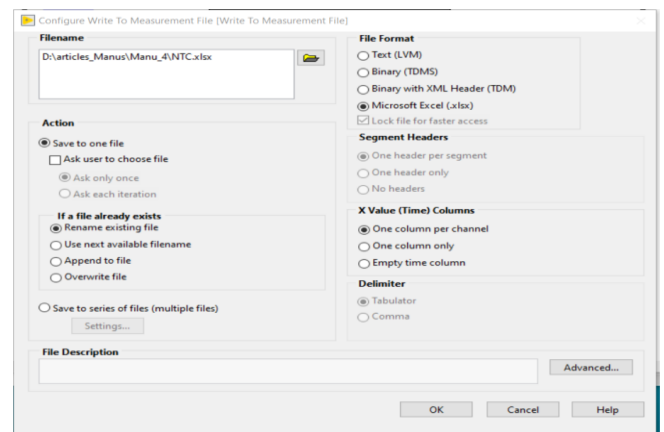
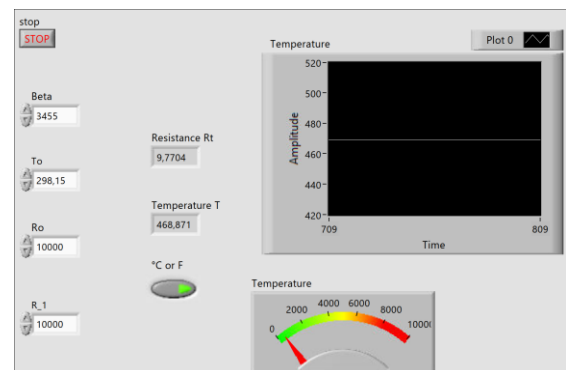
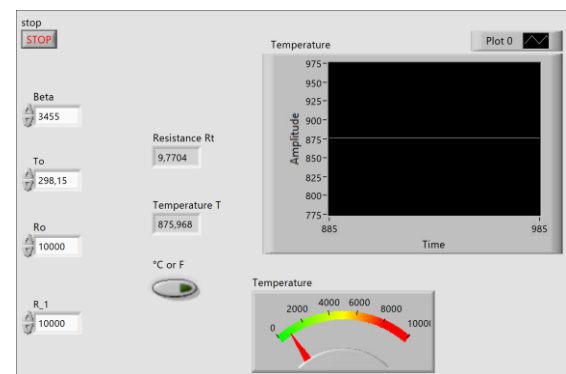


Figure 11. Setting parameters for Data saving for NTC Thermistor



(a)



(b)

Figure 12. Displayed results for an NTC: (a) in $^{\circ}\text{C}$ and (b) in $^{\circ}\text{F}$

C. Type K Thermocouple

A thermocouple consists of two wire legs made from different metals. The wire legs are welded together at one end, creating a junction. A thermocouple depicts a voltage at its terminals when submitted to a certain temperature. There are many types of thermocouples: type B, type E, type J, type K, type N, type R, type S and type T. Each thermocouple has its reference table which gives the temperatures and the voltages (in μV or mV). For this experiment, a type K thermocouple is used. Its reference table has been downloaded from the Website of REOTEMP Instruments Company [12-14].

In order to obtain the relationship between the measured temperature (T) and the output voltage (V), MATLAB® software has been used. With its curve fitting tool (cftool), the polynomial equation shown in equation (7) is obtained. The curve fitting tool window is shown in figure 13 and the plotting curve $T=f(V)$ in figure 14. The wiring diagram and the wiring image are shown in figures 15 and 16 respectively.

$$T = aV^5 + bV^4 + cV^3 + dV^2 + eV + f \quad (7)$$

With the obtained coefficients: $a = 4.336 \times 10^{-6}$; $b = -0.0005$; $c = 0.02972$; $d = -0.6431$; $e = 29.09$ and $f = -1.751$, at $R^2 = 0.9998$.

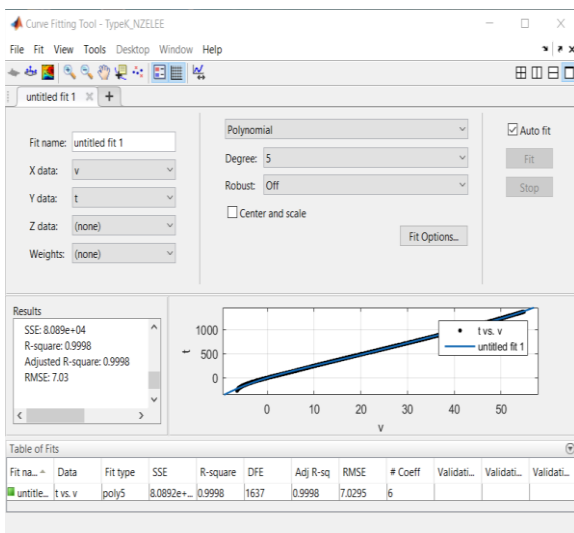


Figure 13. Fitting session window for type K thermocouple

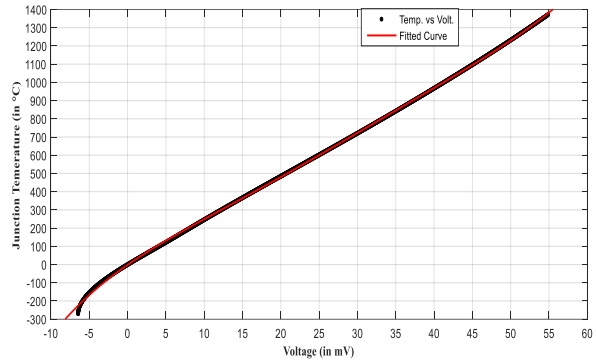


Figure 14. Temperature as the function of the output voltage for type K thermocouple

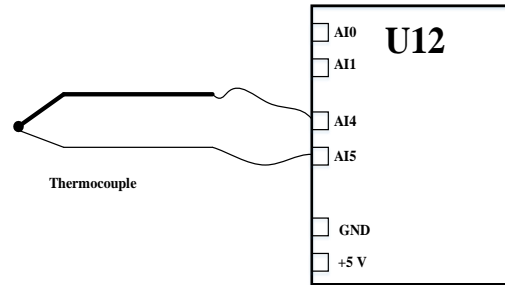


Figure 15. LabJack Wiring Diagram for the thermocouple

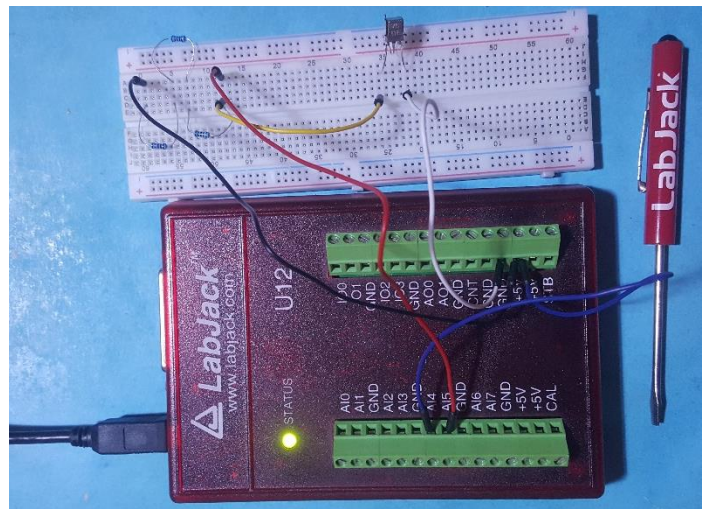


Figure 16. Wiring Image of a type K thermocouple to LabJack U12

For the LabVIEW model as shown in figure 17, students should follow the following steps:

- Step 1: After running LabVIEW 2019, click on **Create Project**, then **Blank VI**. Two windows will be opened: the Block Diagram window and the Front Panel window. Both of them will be used simultaneously.
- Step 2: Right in the Block Diagram window, then put the cursor on **Structures** in Programming Function. Then click on **While Loop** to draw the while loop rectangle for continuous running. Right click on the red button and select **Create Control** to add a Stop control button.
- Step 3: Right click in the while loop, then put the cursor on **Structures** and select

Formula Node. Draw the formula node rectangle inside the while loop.

- Step 4: Right click on the left side of the formula node rectangle to add inputs. For this experiment, there are seven inputs to add: Vo, a, b, c, d, e and f.
- Step 5: Right click on the right side of the formula node rectangle to add outputs. For our case, there are three outputs to add: V (read voltage Vo converted in mV), T_C (the temperature in °C) and T_F (the temperature in °F).
- Step 6: From the Front Panel window, right click, then put the cursor on **Numeric** and select **Numeric Control** to add numeric block to the four input constants: a, b, c, d, e and f.
- Step 7: From the Block Diagram window, right click outside the formula node rectangle, then put the cursor on **Addons**, then on **LabJack** and select **EAnalogIn.vi**, to add two LabJack analogue input block. For input Vo, set the channel of the LabJack block to **4-5 Diff** and the gain to **4(+/- 5 V)**.
- Step 8: From the Front Panel window, right click, then put the cursor on **Numeric** and select **Numeric Indicator** to display the voltage Vo and the measured temperature T (in °C or in °F). For the waveform display of the temperature, right click, then put the cursor on **Graph** and select **Waveform Chart**.
- Step 9: For recording the data to a file (Excel file for example), from the Block Diagram window, right click, then put the cursor on **File I/O** and select **Write Meas File**. The setting window will appear as shown in figure 6. Do necessary configuration and click on **Ok**.

The final and correct model should be like the one shown in figure 17. Click on the **Run** button to run the acquisition process, with the LabJack unit connected to the USB port of the computer. The displayed results are shown in figure 18. In figure 18 (a), the temperature is displayed in degrees Celsius (°C), while in figure 18 (b), it is displayed in degrees Fahrenheit (°).

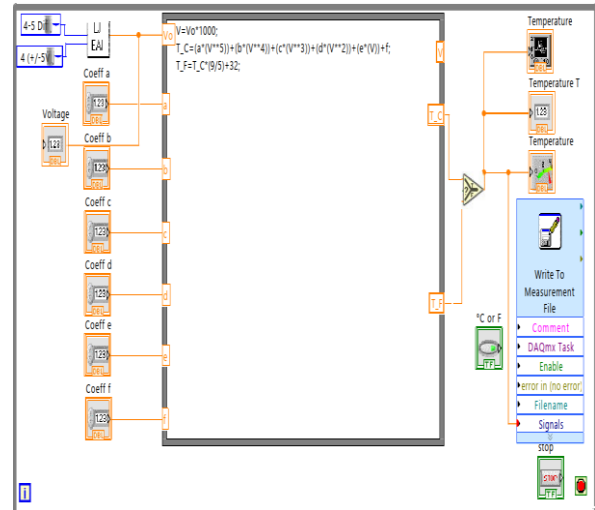


Figure 17. LabVIEW Block Diagram for a type K thermocouple

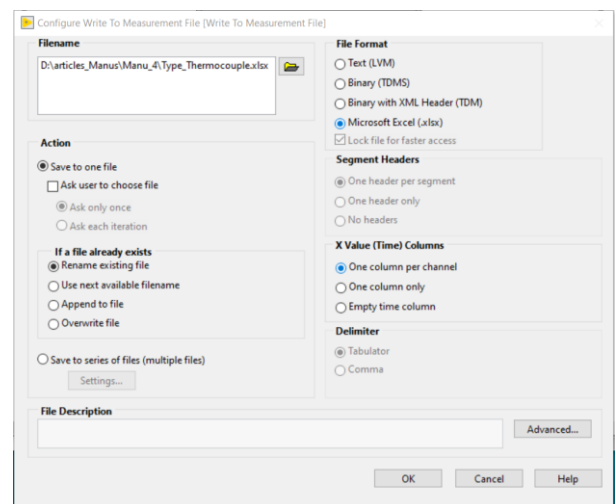
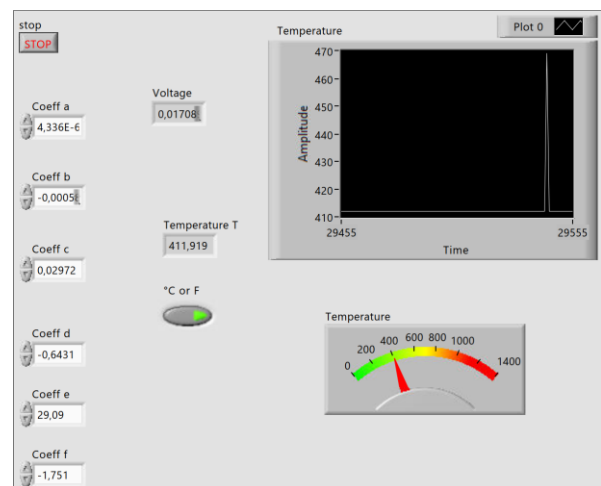
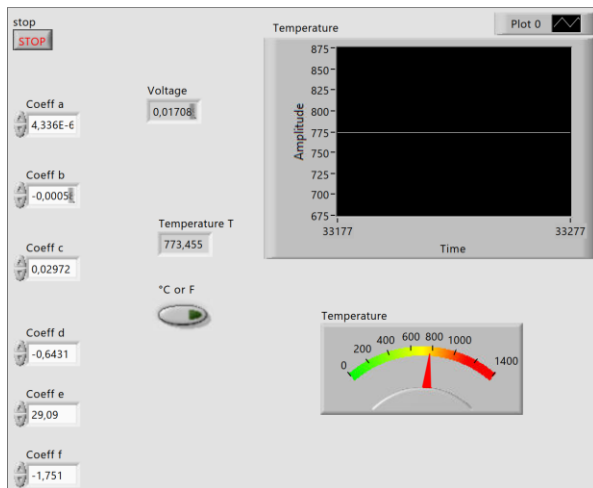


Figure 18. Setting parameters for Data saving for a Type Thermocouple



(a)



(b)

Figure 19. Displayed results of a type K thermocouple: (a) in $^{\circ}\text{C}$ and (b) in $^{\circ}\text{F}$

CONCLUSION

The implementation of LabJack U12 data acquisition unit was well done by the students during the lab practice of instrumentation course. During the workshops, students have been familiar with the hardware working skill and the software working skill. For hardware skill, students worked on three types of temperature sensors: a resistive temperature detector, a thermistor and a type K thermocouple. Each sensor has its specific working principle and it allowed students to understand it practically. The software skill was carried out on LabVIEW 2019 version which helped to display the measured temperature on a personal computer. Today, LabJack U12 is made popular for most engineering students who are using it in many applications. At the end of these exercises, students can further their skill by developing various control processes. However, in order to reinforce the implementation of the used sensors, a comparative study can be carried out using various types of data acquisition units.

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