MECH420

Sensors and Actuators

Laboratory Manual for Experiment 1

Fall 2020

The University of British Columbia

Department of Mechanical Engineering

Table of Contents

Laboratory Requirements and Tips

Since the course MECH 420 is conducted on-line during the current academic year, the laboratory requirements from the students have been modified.

You will receive a description of the lab (in the current manual), an video of the experimental procedure, and the data collected from that procedure. Within a week of receiving the data, you should send by email to one of the TAs, the following:

1. A complete lab report (which includes data analysis, results, and discussion of the results), as a pdf document. *Note*: The provided data will be different for each student.
2. Answers to a set of further questions provided to you for the particular lab experiment.

The above two items will be your individual effort and contribution. Under no circumstances should you consult other students when preparing these items. However, you may use any course material, other books and publications, and any other information that is available on line (for example, equipment catalogs, data sheets, marketing material). Also, you may communicate with the TA, if necessary.

Laboratory Report

Each student will prepare an individual report. On the first page of your report indicate your name, student number, your lab group, the date on which you received the data for the particular experiment, and the name of the TA who communicated with you regarding the particular laboratory experiment.

Preferable, the report should be typed. Some handwritten parts are acceptable, if the writing is very clear.

For each experiment, document the experimental setup and experimental conditions such as sampling rates for data acquisition.

Document the mathematical operations you have performed on the data by providing the corresponding equations in your report along with the results. Always report the correct units for the data and the results. Make sure that all graphs are properly labelled.

In the report, discus your results and indicate the drawn conclusions.

The lab report, along with your answers to the posed questions, should be sent to the TA, by email, as a pdf file, no later than 1 week after receiving your laboratory data.

Laboratory Exercise #1: Proximity Sensors for Object Detection

Learning Objectives

The main objectives of this laboratory exercise are:

- To become familiar with the principles of the LED proximity sensor, eddy current inductive proximity sensor, capacitive proximity sensor, and infrared reflective object detector,
- To learn how to calibrate the sensors and determine their static transfer (input-output) characteristics,
- To recognize the limitations and possible areas of application for these 4 sensor types
- To learn methods of analyzing data obtained from these sensors.

Background

Proximity sensors are commonly used in industry to detect the presence or the distance of an object without making physical contact. The output signals of four different types of proximity sensors have been acquired, and provided to you, along with a video of the entire procedure. You will examine, and analyze this data, and compare and discuss the results. The sensors operate on different physical principles, making them more or less suitable for specific applications. The sensors will be used to scan various test specimen profiles of different materials in order to characterize the sensor signals for different materials and geometries. The PC-based data acquisition is performed using the software package LabVIEW (see Appendix A and Appendix B).

1. System Overview

Figure 1.1 shows a schematic diagram of the setup used in this laboratory experiment. A test specimen profile is moved under the proximity sensors, while a position sensor measures the position of the profile. The position signal, the proximity sensor signals along with the signal from a reference sensor are fed into a signal conditioning interface. The conditioned voltage signals are read into a PC via A/D conversion through a data acquisition board. Data acquisition occurs using the software package LabVIEW.

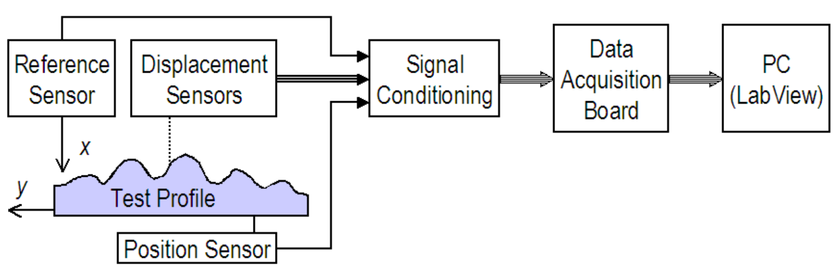


Figure 1.1: Schematic diagram of the measurement system for proximity sensor characterization.

2. The Proximity Sensors

2.1 Infrared Reflective Object Sensor

Infrared (IR) radiation corresponds to wavelengths in the electromagnetic spectrum that are longer than the wavelengths of visible light. IR radiation cannot be seen but it can be detected. Objects that generate heat also generate infrared radiation and those objects include animals and the human body whose radiation is the strongest at a wavelength of 9.4 µm. Infrared radiation in this range will not pass through many types of material that are transparent to visible light such as ordinary window glass and transparent plastic. However infrared radiation can pass through, with some attenuation, certain materials that are opaque to visible light such as germanium and silicon. An unprocessed silicon wafer makes a good IR window in a weatherproof enclosure for outdoor use.

The IR sensor considered here (OPB704 by Optek Technology Inc.) is made of an infrared emitting diode and a phototransistor. The IR emitting diode gives off IR radiation in the general direction of the target object, and the phototransistor gathers the reflected IR radiation, as shown in Figure 1.2.

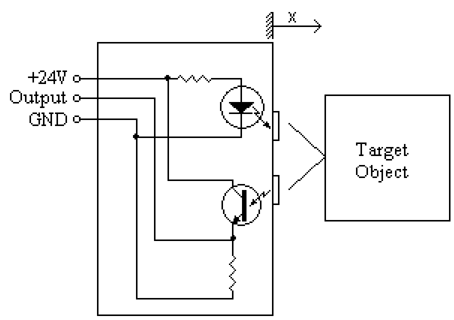


Figure 1.2: A typical configuration of an infrared reflective object sensor.

The intensity of the signal received by the photodetector will depend on position x of the target object. In particular, if $x = 0$, the signal path between the emitter and the receiver will be completely blocked off and the signal intensity at the receiver becomes zero. As x increases, the intensity of the received signal will increase, because more and more of the infrared signal will be reflected towards the receiver. The signal intensity will reach a peak for some distance x_p, where the signal path from the emitter to the receiver via the reflecting surface is mainly unobstructed, as shown in Figure 1.3 [1.1]. At larger distances the effect of signal distribution over a larger solid angle in space will be predominant; hence, the intensity of the received signal will drop. For $x > x_p$ the proximity-intensity (x-I) curve for an optical or infrared proximity sensor will therefore follow a nonlinear relationship, which may be approximated by

$$I \sim 1\big/(x^2 + (s/2)^2),$$

where s is the distance between the emitter and the receiver. As a first approximation we can assume that the current through the collector-emitter circuit is proportional to the infrared signal intensity. This current causes a voltage across the emitter-ground resistor, which is used as the sensor signal. The infrared reflective sensor used here is the type OPB704 by Optek Technology Inc. with s = 5 mm.

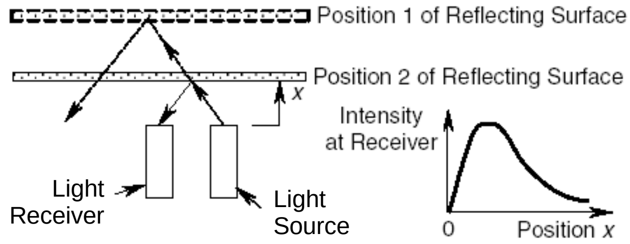


Figure 1.3: Operation and transfer characteristic of a reflective object sensor [1.1]. ***Note*: Light here may mean infrared radiation as well.**

2.2 LED Displacement Sensor

The LED displacement detector Z4W-V by Omron measures the distance of an object through light reflecting off that object in a similar way as the infrared reflective object sensor described above. Some of the differences are the wavelength of the light, which is now in the visible spectrum, and the integrated signal amplifier. The red LED of the sensor emits a light beam. A light detector (phototransistor) measures the intensity of the reflected light and an integrated amplifier converts this signal into a 4-20 mA current output. An external load resistor (300 Ω) converts the current into a voltage signal that is fed into the data acquisition system. The amplified signal is almost linear with distance (up to a certain limit) as shown in Figure 1.4.

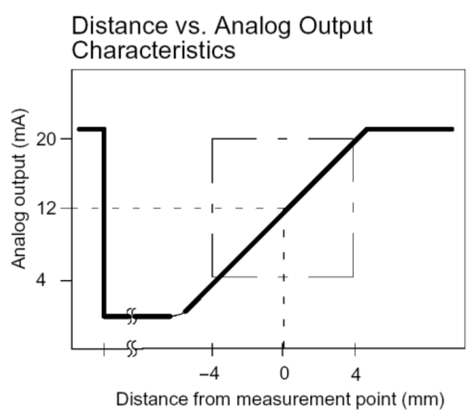


Figure 1.4: Transfer characteristic of the Z4W-V LED displacement sensor with integrated signal amplifier, provided in the data sheet by Omron.

2.3 Eddy Current Proximity Sensor

If an electrically conductive medium is subjected to a fluctuating magnetic field, eddy currents are generated in the medium. The strength of eddy currents increases with the strength of the magnetic field and the frequency of the magnetic flux. Figure 1.5 shows a schematic view of an eddy current proximity sensor, which uses this principle [1.1].

Unlike variable-inductance proximity sensors, the target object of the eddy current sensor does not have to be made of a ferromagnetic material. A conducting target object is needed, but a thin film of electrically conducting material—such as household aluminum foil attached to a non-conducting target object—is sufficient. The probe head has two identical coils, which form two arms of an impedance bridge. The coil closer to the probe face is the *active coil*, and the other coil is the *compensating coil*. When the target object is moved close to the sensor, eddy currents are generated in the conducting medium in the object because of the radio-frequency magnetic flux from the active coil. The magnetic field of the eddy currents opposes the primary field, which generates these currents. Hence, the inductance of the active coil increases, creating an imbalance in the bridge circuit whose two arms are the active coil and the passive coil. The resulting output from the bridge is an amplitude-modulated signal containing the radio-frequency carrier. This signal is demodulated by removing the carrier signal. The resulting signal is a measure of the position of the target object. As indicated in Figure 1.5, the impedance bridge, demodulator, and low-pass filter are usually built into the sensor, so that the sensor gives a standard analog voltage as the output signal.

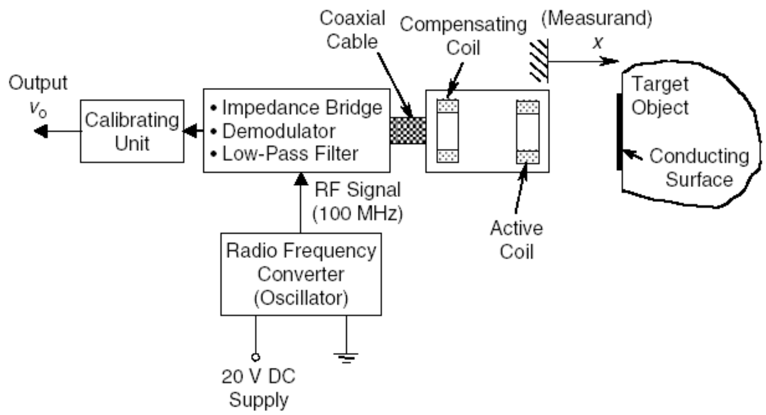


Figure 1.5: Schematic diagram of an eddy current proximity sensor [1.1].

The eddy current sensor used in this laboratory is an AK9-10 type proximity sensor produced by Automation Direct with a 0 – 10 V output signal.

2.4 Capacitive Proximity Switch

Capacitive proximity sensors use the change in capacitance when an object is placed in front of the sensor head. This is because the object becomes part of the medium through which the electrostatic field generated by the capacitor electrodes (plates) passes. A capacitive sensor is sensitive to most materials: dielectric materials such as glass, rubber and oil, and conductive materials, such as metals, fluids containing ions and moist wood.

When an object comes near the sensing surface, it enters the electrostatic field of the two electrodes (of the capacitor) and changes the capacitance, which is part of an oscillator circuit. As a result, the oscillator begins to oscillate. The trigger circuit reads the oscillator’s amplitude and when it reaches a specific level (threshold), the object is detected, and the output state of the capacitive proximity switch changes. Figure 1.6 shows the schematic diagram of such a capacitive proximity switch. Such switches normally have a screw on the backside of the sensor, which allows changing the signal threshold for detecting a target object. As the target moves away from the sensor the oscillator’s amplitude decreases, switching the sensor output back to its original state of no object.

Without some sort of compensation, any material entering the sensing field (electrostatic field of the capacitor) can cause an output signal. This includes water droplets on the sensor face, dirt or dust, and other contaminants. A compensation electrode in the sensor solves this problem by creating a compensation field. When contaminants lie on the sensor face, both fields are affected equally through a capacitance increase. The sensor accounts for this common increase, and corrects the output. The compensation field is very small and does not extend very far from the sensor. When a target enters the sensing field of the sensor, the compensation field is unchanged while there is effect from the target.

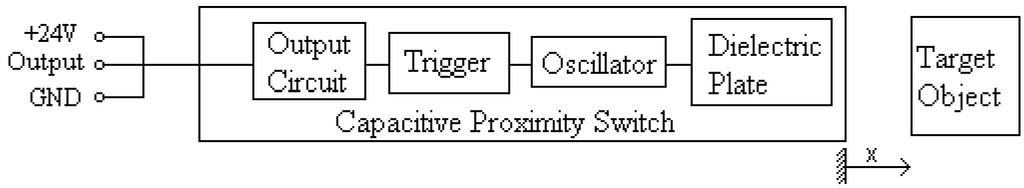


Figure 1.6: Schematic diagram of a capacitive proximity switch.

The sensor used in this experiment is the CT1-AN-1A capacitive switch by Automation Direct. When activated, the 24 V supply voltage of the sensor is present at its output. In order to feed the output signal into the DAQ board, which has a maximum input of 10 V, this output voltage signal is limited by using an 8.2 V zener diode. The current to this diode is limited by a 1 MΩ resistor, as shown in the electric diagram in Table 1.2.

3. The Components of the Experimental Setup

3.1 The Proximity Sensor Characterization Apparatus

The apparatus in the proximity sensor characterization experiment, shown in Fig. 1.7, consists of a base, linear crank stage, profile mounting platform, and sensor support structure. Profiles of various shapes and materials are placed on the profile mounting platform, which is attached to the moving section of the linear crank stage. As the platform is moved along the crank stage, it carries the selected profile under the sensor support structure, where a number of proximity sensors and a digital dial indicator are placed. During this procedure, the proximity sensor signals along with the reference signal from the digital dial indicator are recorded by the PC. The position of the profile is simultaneously recorded using the linear potentiometer connected to the linear crank stage.

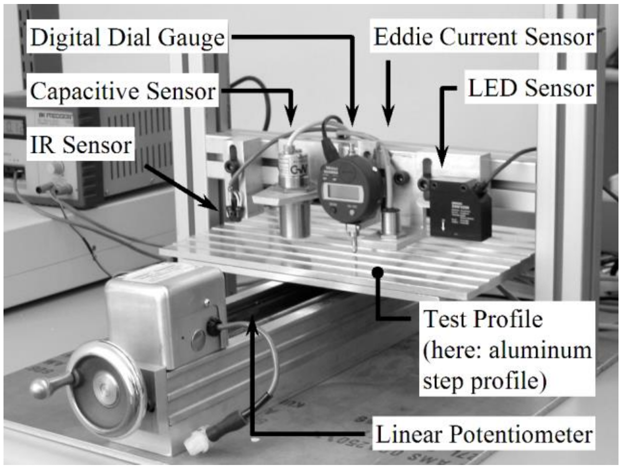
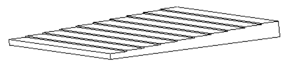


Figure 1.7: The experiment apparatus for proximity sensor characterization.

3.2 The Test Profiles

The following 6 test specimens are passed under the row of proximity sensors during this experiment:

Aluminum Specimen with Step Profile



This specimen is made of aluminum, and its profile consists of a sequence of 10 flat steps along its 203.2 mm length. At the thinnest step, the profile is 6.35 mm thick. Each step is 20.32 mm long and 1.25 mm high. This profile has an identical thickness along its 330 mm width.

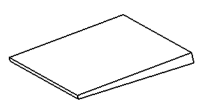
Delrin (trade name, which is a plastic) Specimen with Step Profile

This specimen has a Step Profile that is identical to the Aluminum specimen, except that it is made of black Delrin.

Lexan (trade name, which is a thermoplastic) Specimen with Flat Profile

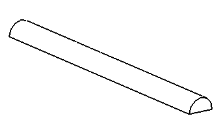
This specimen is made of Lexan and is mounted in different way than the other profiles. Since Lexan is difficult to machine while maintaining its transparent surface finish, and hence, its profile is left flat. The experimental procedures describe how to mount this profile on the sensor support structure, and how to move the sensors onto the moving platform. In this way the distance between the sensors and the profile can be manually adjusted using the crank. The Lexan profile is 12.7 mm thick along most of its length, with 8.2 mm flanges to fit in the t-slot.

Aluminum Specimen with Ramp Profile (currently not used)



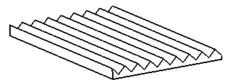
This specimen is made of aluminum and its profile is an inclined plane. The thickness of the profile is 6.35 mm at its thinner end, ramping up along its 203.2 mm length to 17.6 mm. The thickness remains constant along the 330 mm width of the profile.

Aluminum Specimen with Round Profile (currently not used)



This specimen is made of aluminum and its profile is a semicircle. It consists of a half rod of aluminum of diameter 35.2 mm and a flat bottom. Like the other profiles, it is 330 mm wide.

Aluminum Specimen with Triangle Profile (currently not used)



This specimen is cut from an aluminum block and its profile is a series of triangles. The block is 18.35 mm thick at the peaks of the triangles, and 6.35 mm thick in the valleys of the triangles. The angles at all of the peaks and valleys are 90°, so each inclined plane is 45° from the horizontal plane. The block is also 203.2 mm long in the direction of the inclines and 330 mm wide along the direction of equal thickness.

3.3 The Linear Potentiometer

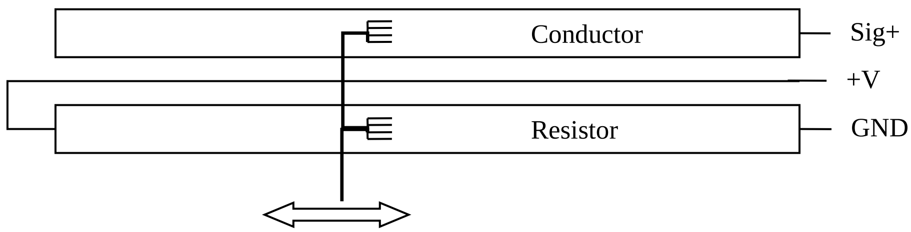


Figure 1.8: Linear Potentiometer.

The linear potentiometer is used to measure the position of the profile mounting platform as it is moved by the linear crank stage. A voltage of 10 V is applied across a fixed resistor, which is an open rail along the length of the linear crank stage. This rail has a constant resistance per unit length, so the voltage at any point along its length can be determined as it is a voltage divider. The moving stage has two brushes attached to it, which are electrically connected (Figure 1.8). The first brush touches the open resistance rail, while the second brush touches the conducting rail running parallel, so that the signal voltage on the conducting rail is proportional to the stage position.

3.4 The Digital Dial Gauge

The digital dial gauge measures a distance through physical contact with its retractable tip. It can be set to measure in mm or inches, and the zero point can also be set using touch buttons on the front of the indicator. In addition, the direction of positive displacement can be set with a small button. The digital output of the digital indicator follows the Digimatic protocol, which has been developed by Mitutoyo for their sensors. When the request line of the dial indicator’s cable is pulled low, the indicator responds by transmitting its signal serially on the data line, along with a synchronous clock signal on the clock line. The data signal contains formatting information as well as a digital number representing the measurement itself, which has units of either mm or inches, depending on which measurement system has been manually selected on the dial indicator. The tip of the digital dial gauge has a diameter of 4 mm.

3.5 Graphical Software Tool as Signal Interface: LabVIEW

PC-based data acquisition is performed using National Instruments LabVIEW. National Instrument LabVIEW is a powerful graphical development environment for creating flexible and scalable test, measurement, and control applications. The integrated

LabVIEW environment is used to interface with real-world signals and acquire data. A short introduction to LabVIEW is given in Appendix A and Appendix B.

3.6 The Data Acquisition Board

The data acquisition (DAQ) board used in this experiment and all subsequent experiments is the National Instruments M-Series PCI-6221. This DAQ board has 16-bit resolution for all of its analog inputs and outputs. The input and output ranges can be specified through software anywhere between -10V and +10V. Setting a smaller range within this maximum range will increase the absolute resolution, as the 16 bits will be redistributed across the specified range.

3.7 The DAQ Interface/Signal Conditioning Box

The signal conditioning box, shown in Fig. 1.9, is used as an interface to the DAQ card, which is located in a PCI slot inside the computer. It provides 6 channels of filtered analog input (low-pass filter with 200 Hz cut-off frequency), 2 channels of unfiltered analog input, 2 channels of analog output, 2 encoder interfaces, and 1 digital input/output connector. The digital connector provides 3 digital inputs and 3 digital outputs.

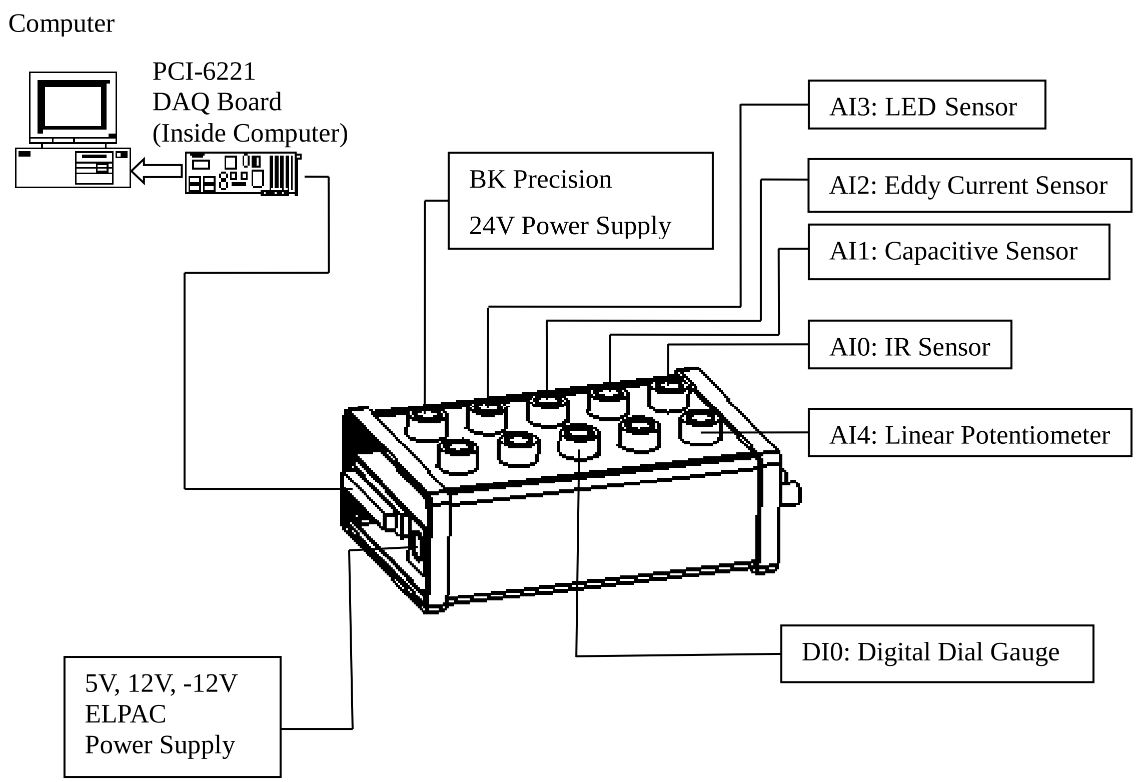


Figure 1.9: The Connection Diagram of Experiment Setup; AI: analog input, DI: digital input.

The filtered analog inputs are available using 6 of the 8-pin CPC connectors on the top of the DAQ Interface Box. The pin configuration of these connectors is given in Table 1.1.

Table 1.1: Pin configuration of data acquisition interface input channels.

Pin	Description
1	GND
2	+24V
3	
4	
5	+10V
6	Signal -
7	
8	Signal +

The signal conditioning used on these analog channels is shown in Fig. 1.10. The second order low-pass filters have a cut-off frequency of ~200 Hz. The gain of the signal conditioner is 1.

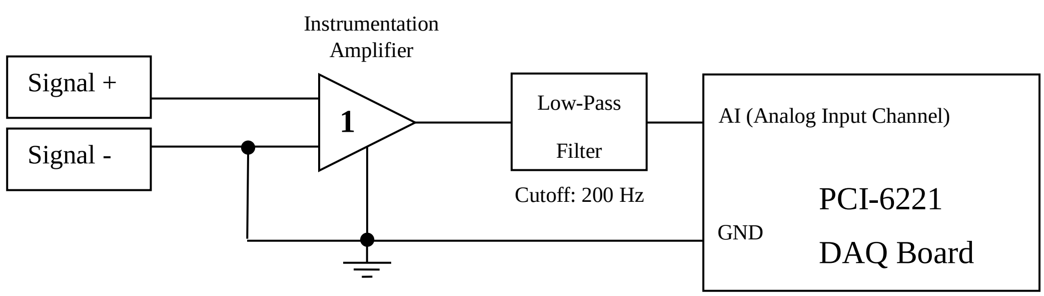
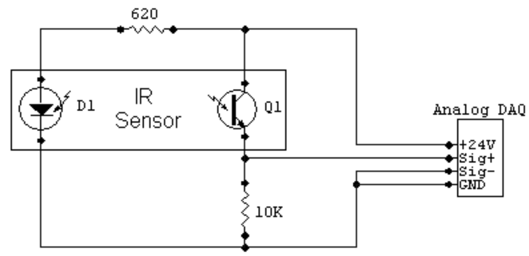
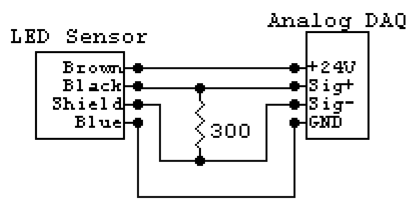
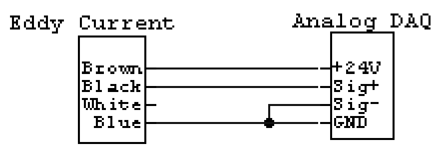
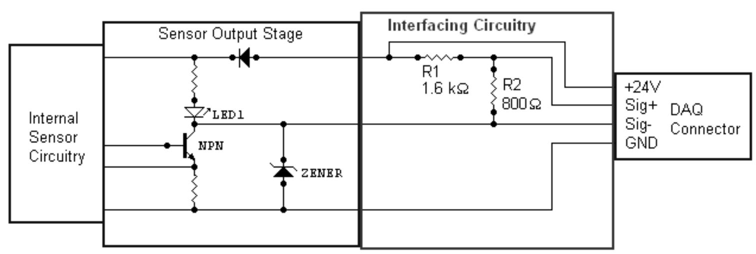
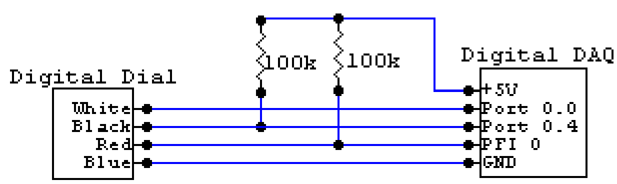


Figure 1.10: Signal conditioning for the filtered input channels of the data acquisition interface.

3.8 The Sensor Connection Diagrams

All cables connecting the sensors to the data acquisition interface box, including circuitry, have been prepared and are used directly for the experiments. The connection diagrams for the proximity sensors and for the digital dial gauge are given in Table 1.2.

Table 1.2: Connection Diagrams for the proximity Sensors and the Digital Dial Gauge with the data acquisition interface.

<table>
<tr><th>Sensor</th><th>Connection Diagram</th></tr>
<tr><td>IR Reflecive Object Sensor</td><td>
</td></tr>
<tr><td>LED Sensor</td><td>
</td></tr>
<tr><td>Eddy Current Sensor</td><td>
</td></tr>
<tr><td>Capacitive Sensor</td><td>
</td></tr>
<tr><td>Digital Dial Indicator</td><td>
</td></tr>
</table>

4. Experiments

4.1 System component list

1. One infrared reflective object sensor
2. One LED proximity sensor
3. One eddy current proximity sensor
4. One capacitive proximity switch
5. One digital dial gauge, used to provide a reference signal

6. One linear potentiometer
7. Sensor mounting platform
8. Linear slide with crank handle and profile mounting platform
9. A computer with the LabVIEW system (including the data acquisition board)
10. Data acquisition interface box with signal conditioning circuitry (200 Hz), a BK Precision power supply for 24 V and an ELPAC 5 V, 12 V, -12 V power adapter
11. Two step profiles (aluminum, Delrin)
12. One flat test piece of transparent Lexan
13. Three additional aluminum profiles (ramp, triangular, semicircular), which are all not being used.

Part A: Calibration of the Linear Potentiometer

The linear potentiometer gives a reference signal for the position of different profiles as they travel along the proximity sensors. This reference signal is calibrated as follows.

Experimental Procedure

1. We have developed a LabVIEW program that acquires a positive voltage signal from one sensor (potentiometer). Acquisition of this signal starts upon pressing a START button, and it ends upon pressing a STOP button. The signal is continuously displayed on the screen, and after acquisition it is written to a file. This is accomplished by using the ToExcel.vi subprogram, which is available in the 'C:\Mech 420\Useful Programs\' folder. Details regarding how to use this function, it is added to the block diagram of the program, press Ctrl-H is pressed while hovering the mouse over it. To add the function to the block diagram, we go to the block diagram and choose "Select a VI…" from the All Functions tab on the function palette. Then we find the correct folder and select ToExcel.vi using the dialog box that pops up. Then the cursor becomes the block symbol of ToExcel.vi; we can click anywhere on the block diagram to place it there. We should also know how to modify the sampling rate and signal range.
2. The linear potentiometer is already connected to the data acquisition board via the signal conditioning board. We must verify at this stage that the signal conditioning board is connected to its power supplies. A ruler is used as a reference and we move the test specimen mounting platform to 10 different positions, while acquiring 100 data values for each position. Here we include the most extreme potentiometer positions as well.

Analysis

Experimental data are provided to you (which are different for each student). The analysis of this data is a key exercise that is done by you, and it should be presented in detail in your report. The student should be prepared to explain their procedures, when communicated by a TA. The failure to provide proper explanation will lead to reduction of the grade for the particular experiment.

1. Calculate the average value and the standard deviation for the values of each data set.
2. Plot the sensor signal as a function of the linear position.

3. Determine the equation for the best linear fit of the data (i.e., linear regression line) using the least squares error method (see Section 4.2.3 of the textbook [1.1]). This is the linear calibration curve (static transfer characteristic) of the sensor as a function of the position (do not forget to include the correct units).
4. Calculate the maximum absolute nonlinearity error of the sensor data and relate it to a position error.

Part B: Calibration and Application of the Proximity Sensors

This tasks has been done already. We measure the signals of the proximity sensors for different profiles of the test specimens made from different materials. we use these measurements to calibrate the sensors. You must explore the limitations of the different sensor types with respect to their applications for object detection.

Experimental Procedure

For all data acquisition experiments, we have inspected the data to make sure that we record the signals with sufficient temporal and amplitude resolution without gathering an unmanageable amount of data (i.e., we choose a proper sampling frequency!).

We turn on the dial indicator before pressing "run" in LabVIEW.

1. We move the platform to the end farthest away from the crank handle. Then we mount the aluminum specimen with the step profile on the linear slider with the thickest end toward the back of the apparatus. Next we move the slide back to the end closest to the crank handle. We do this carefully, not to damage the digital dial indicator by pushing the block into it. Specifically, we lift the moving leg of the indicator before cranking the slider into position. During all the following procedures, we only let the tip of the digital indicator go down a profile.
2. Note that the LED sensor is offset vertically from the digital dial indicator by 20 mm, and the IR sensor is offset by 7 mm in order to keep these sensors near their linear range. We need this information to compare the response of these sensors to their data sheets.
3. We open LabVIEW from the desktop.
4. On the main LabVIEW window, we click Open…
5. We select C:\Mech420\Lab1\Lab1.vi and click Ok.
6. We select an adequate data sampling rate.
7. We run the VI by clicking the arrow at the top of the screen.
8. We crank the handle to move the profile under the sensors.
9. We adjust the threshold of the capacitive switch by turning the adjustment screw so that the switch changes state approximately in the middle step height of the step profile. Then we push the STOP button in LabVIEW. We don`t save the collected data. We will repeat this run with the correct setting of the capacitive switch. For this purpose, we bring the step profile back to its original position.
10. We run the VI by clicking the arrow at the top of the screen.
11. We crank the handle to move the profile under the sensors.

12. When the linear slide is fully extended, we push the STOP button on the computer to stop logging data.
13. When prompted, we enter a file name and location to store the results for this profile.
14. We repeat the previous steps with the Delrin (opaque plastic) step profile. We use the four screws provided to hold the Delrin profile flat against the mounting platform. The screws are inserted from the bottom of the platform and threaded into the four corners of the profile.
15. We inspect the data to make sure we have all the information that we need.
16. Now we rotate the sensors by 90° and mount them onto the mobile platform in order to move them against the transparent Lexan block that will be mounted vertically. For this, we loosen the fasteners at both ends of the sensor mounting bar. We slide the mounting bar up and out of the vertical T-slot posts. We mount this bar on the profile mounting platform using the 8.2 mm holes and 8 mm bolts provided. The sensing face of all the sensors will be pointing away from the crank handle.
17. We crank the handle until the profile mounting platform (with sensors attached) is as close to the crank handle as it can be.
18. We slide the Lexan block into the T-slot posts where the sensor support bar used to be. We slide it all the way down until it sits on the profile mounting platform, causing the block to lie in the sensing path of the proximity sensors.
19. We crank the handle until the tip of the dial indicator touches the Lexan block.
20. We run the VI by clicking the arrow at the top of the screen.
21. We slowly crank the handle, moving the sensors toward the Lexan block, until the dial indicator is fully retracted.
22. We push the STOP button on the computer to stop logging data. When prompted, we enter a file name and location to store the results for this profile.

We save all the data, which are provided to you for analysis and completing the lab report requirements.

Analysis (An Important Part of the Lab Report)

1. Prepare one graph for each of the 2 step profiles with all proximity sensor signals (in V) and the dial gauge output (in mm) as a function of the profile position by using the calibration equation for the potentiometer from above. Give general comments about the signal ranges and shapes including the signal from the digital dial gauge.
2. Now use about 10 sensor readings for the IR sensor and the LED sensor around the centre of each step for the 2 step profiles, and calculate the average voltage reading for each distance. Use these values to plot the sensor response $V_i(x_i)$ for both proximity sensors for the two step profiles and the Lexan sample. That means, plot for both sensors the sensor signal as a function of distance measured by the digital dial gauge. Include the sensor response for all three samples in one single plot per sensor. For the Lexan sample you can use the data as measured.

3. Determine the calibration equations $x_i(V_i)$ for the LED sensor for each one of the 3 samples (2 step profiles and the Lexan sample).
4. Compare your observations for all 4 sensors with the specifications in the data sheets.
5. What type of sensor would you use in the following situations to detect objects present on a conveyor belt? Explain.
    a) Detecting the presence of a conductive object.
    b) Determining the approximate thickness of an opaque object.

5. Additional Exercises (These should be included at the end of your report)

1. Find the prices for all 4 sensors and provide the respective sources.
2. Find the data sheets for the 4 proximity sensors on the internet. How suitable are these 4 sensors for measuring the location of an object within the range of 0 to 10 mm?
3. For the linear potentiometer, provide an electric diagram that includes the potentiometer, the data acquisition interface (Fig. 1.9 and 1.10) and the DAQ board inside the computer. Keep in mind that the data acquisition interface provides a voltage to the sensors and also performs signal conditioning (Fig. 1.9 and 1.10 and Table 1.1). Make sure that the circuit diagram shows how the sensor signal is passed to the DAQ. Indicate the connection cables between the potentiometer and the data acquisition interface and between the data acquisition interface and the DAQ board.
4. Even in the recommended measurement range, the sensor output (the *measurement*) may not be linear with the *measurand*. Give reasons for this behavior. Indicate ways to correct this.

Appendix A

LabVIEW Basics

This section provides a brief introduction to LabVIEW. It describes the basic idea of LabVIEW programming, and it explains where to find certain key functions and structures, such as loops and mathematical operators. These tutorials are recommended for those who have had little experience using LabVIEW.

The LabVIEW Environment

Since LabVIEW is often used to simulate instrumentation, all LabVIEW programs are called Virtual Instruments (VIs). Each VI has two components: a Front Panel, and a Block Diagram. The Front Panel is the user interface of the VI. This is where we create displays such as graphs and tables, as well as inputs from the user such as buttons and sliders. When a VI is run, the Front Panel is the window that shows up, and that the user interacts with. The Block Diagram is where the programming is done. All of the objects on the Front Panel are represented by a block on the Block Diagram. Here, the object blocks are connected by wires. When editing a VI, often only the Front Panel is opened initially; to open the Block Diagram, we select Window→Show Block Diagram.

Programming of a Sample VI

As an example of how to use LabVIEW, a program can be created that counts upward from zero by one integer every second until a Stop button is pushed. The first task is to create the front panel. For this simple program, all that is needed on the Front Panel is a Numeric Indicator, as well as a Stop Button. To place these, we right-click on the Front Panel to bring up the Controls palette, then we select Numeric Indicators→Numeric Indicator, as shown in Figure 1.A1.

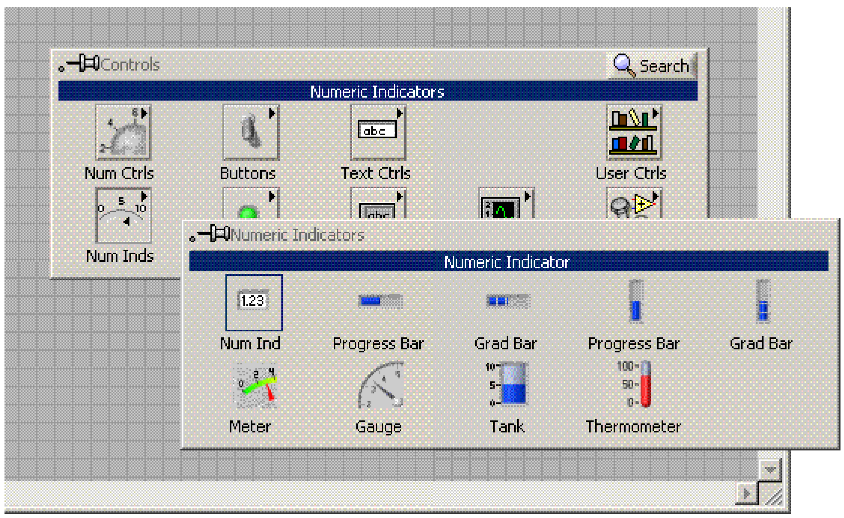


Figure 1.A1 - Numeric Indicator Palette.

After selecting Numeric Indicator, we left-click anywhere on the Front Panel to place the indicator. We will see a number box at the place where we clicked. To move this, we click near the edge of the number box and drag it to wherever we wish.

To create the Stop button, we can similarly right click to access the Controls palette, and then select Buttons→Stop Button. We can place this anywhere on the Front Panel.

Now that the Front Panel has everything it needs, it is time to move on to the Block Diagram. If the Block Diagram is not visible, we select Show Block Diagram from the Window menu. We should immediately notice that there are two blocks on the Block Diagram, one labeled “Numeric”, and the other labeled “Stop”. These two blocks represent the indicators we recently placed on the Front Panel. How we wire these blocks will determine how the indicators on the Front Panel behave.

Since we want the program to count upward in integers until we push stop, a while loop is necessary. To create a while loop, we right-click anywhere on the Block Diagram to access the Functions palette. From there, we select All Functions→Structures→While Loop, and then drag a box around everything that we wish to be inside the while loop on the Block Diagram. Note: We should make the box larger than we need right now, in order to leave room for the wiring we will do. We can resize the while loop box later.

We will notice that along with the while loop box, two other small blocks appeared near the bottom of the while loop. The one on the left looks like a blue 'i' in a blue box, and the one on the right looks like a red stop sign in a green box. The stop sign controls when the while loop ends. It accepts a value of true or false, and when the value wired to the stop sign becomes true, the while loop immediately ends. A stop button gives a true/false output, where it is false when the button is not pressed and true when the button is pressed. The stop button will therefore serve quite nicely as a condition for stopping the while loop. We wire the output of the stop button to the input of the stop sign. At this point we could run the VI by clicking the run arrow near the top of the screen. The VI won't do anything, but we will notice that if we click the Stop button on the Front Panel, the VI will stop running and will return to the edit mode.

The little blue 'i' button near the bottom of the while loop always contains the value of the current iteration of the while loop. For instance, the first time the while loop is executed, it contains the value '0', the second time the while loop is executed, it contains the value '1', and so on. Since this is exactly what we wanted to display on the Front Panel, we can wire it directly to the Numeric block.

The last task is to slow down the execution of the while loop so that it executes just once every second. Otherwise, the numbers on the Front Panel would increment that is too fast to see. To do this, we right click on the Block Diagram. We select All Functions→Time & Dialog→Wait (ms), and click anywhere inside our while loop. This function will wait for a set number of milliseconds, slowing down the execution of the loop. Now we right-click anywhere on the Block Diagram, and select Arith/Compare→Numeric→Num Const, and click somewhere near the Wait block inside your while loop. In the blue box that is placed, we type the number '1000', for 1000 ms. Now we wire up this little box to the Wait block. This will cause the Wait block to wait for 1000 ms, which is 1 second.

Now we run the VI by clicking the run arrow near the top of the screen, and look at the Front Panel. The number in the text box will increment by 1 every second. If we press the Stop button, the VI will stop. We have now finished creating the VI. Our Block Diagram will look similar the one given in Figure 1.A2.

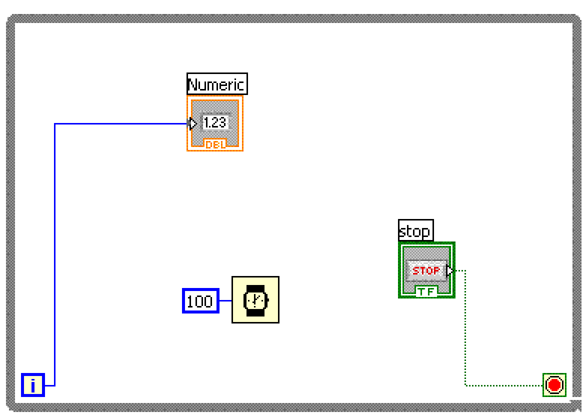


Figure 1.A2 - Example Block Diagram of a counter.

Appendix B

LabVIEW – Analog Data Acquisition

This section will provide a brief description of how to gather analog data from the Data Acquisition (DAQ) card plugged into the PCI slot of our computer. Here it is assumed that we already have a basic understanding of the LabVIEW programming interface, as well as some of the structures such as While and For Loops. An introduction to LabVIEW basics is provided in Appendix A of this lab manual.

The simplest method of data acquisition in LabVIEW 7.1 is to use the DAQ Assistant (see Figure 1.B1). To use the DAQ Assistant, we right-click anywhere on the block diagram of our VI. From the palette that pops up, we select Input→DAQ Assistant. We click anywhere on our block diagram to drop the DAQ Assistant there.

The DAQ Assistant will then open a window to ask us what type of measurement we would like to make. To acquire an analog voltage signal, we click Analog Input from the menu on the right of the popup window. Then we select Voltage from the sub-list that appears. A new list will appear containing various different channels, such as an0, an1, and an2. If more than one DAQ device is installed in the computer, each device will be listed along with its corresponding analog input channels. The DAQ card used for this lab is called 'Dev1 (PCI-6221)'. From this list, we select which channel(s) we would like to acquire a signal from, and then we click Finish.

A setup window will pop up with various configuration parameters (see Figure 1.B2). The most important configuration parameters are the Input Range, Terminal Configuration, Acquisition Mode, and Clock Settings. We enter the range of the signal we will be acquiring in the Input Range boxes. For the proximity sensors used in this lab, the input range is 0V to 10V. We must make sure that the Terminal Configuration parameter is set to Differential.

The Acquisition Mode parameter allows us to select how many samples to acquire, and what kind of timing is used to acquire them. 1 Sample (On Demand) will cause the DAQ Assistant to take a single reading from the specified channel whenever it gets called. 1 Sample (HW Timed) will cause the DAQ Assistant to take a series of single samples at a frequency specified by the Rate (Hz) parameter under the Clock Settings heading. N Samples will cause the DAQ Assistant to take a certain number of samples, and then stop taking samples. The number of samples to acquire is specified by the Samples to Read parameter, and the rate at which to acquire them is specified by the Rate (Hz) parameter. Continuous Samples will cause the DAQ Assistant to continuously take samples at a rate specified by the Rate (Hz) parameter.

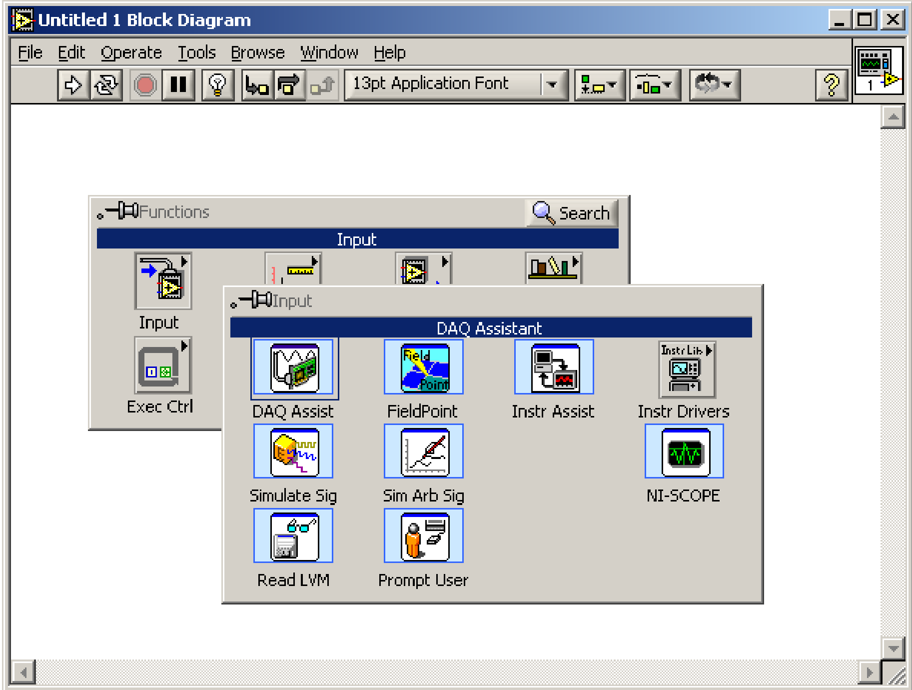


Figure 1.B1 – Selecting the DAQ Assistant.

The simplest Acquisition Mode parameter to use is 1 Sample (On Demand). Once we have selected all of the configuration parameters, we click OK and wait while the DAQ Assistant generates a VI for us. After it has finished generating code, the DAQ Assistant will have a single data output. The data type of this output is Dynamic Data, and will contain all the data acquired by the DAQ Assistant. In order to use that data, we will need to convert it to a regular data type. This can be accomplished by using the Convert From Dynamic Data function, which can be found by right-clicking anywhere on the block diagram and selecting Signal Manip→From DDT.

When the Convert From Dynamic Data function is placed on the block diagram, a window will pop up asking what kind of data we want, and how it should be formatted. For example, we could choose to convert the data into a 1-D array containing the most recent sample from each channel that is being monitored. The data can then be used just like any other data in LabVIEW.

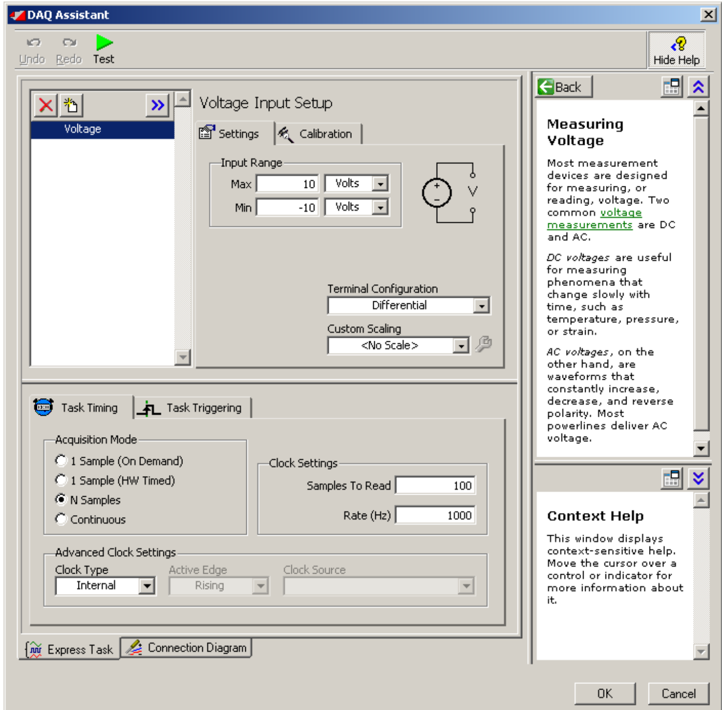


Figure 1.B2 – DAQ Assistant Details.

Reference

[1.1] *Sensors and Actuators: Engineering System Instrumentation*, 2nd Edition, C. W. de Silva, CRC Press, Taylor & Francis, Boca Raton, FL, ISBN: 978-1-4665-0681-7, 2016.

Further Notes:

- **Some results from lab exercises will be used again in later labs**
    - **Example: You will need calibration results from Lab 1 in Lab 4**
- **Lab topics may be relevant in the exams**