Laboratory manual

Virtual Instrumentation Laboratory Platform

UbiLAB

Универзитет "Св. Кирил и Методиј" во Скопје
ФАКУЛТЕТ ЗА ЕЛЕКТРОТЕХНИКА И ИНФОРМАЦИСКИ ТЕХНОЛОГИИ

Hochschule Anhalt
Anhalt University of Applied Sciences

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Introduction

The Remote Virtual Instrumentation Laboratory Platform (RVILP) provides engineers with a versatile platform for conducting a wide range of experiments using standard instrumentation. These include multimeters, power supplies, oscilloscopes, function generators, data acquisition cards, etc. The RVILP operates on an event-driven state machine programming architecture, enabling engineers to initiate specific virtual instruments (VIs) for carrying out dedicated tasks and updating the platform using global variables. This programming approach allows for efficient control and coordination of the experiments. To facilitate seamless communication among the virtual instruments, functional global variables are utilized. These variables serve as a means of sharing information pertaining to physical quantities, measurement units, status and control messages, as well as error control. Remote access to the VIs is made possible through a standard clientless remote desktop gateway, such as Apache Guacamole. This ensures that engineers can conveniently access and control the RVILP from any location, further enhancing the flexibility and usability of the platform.

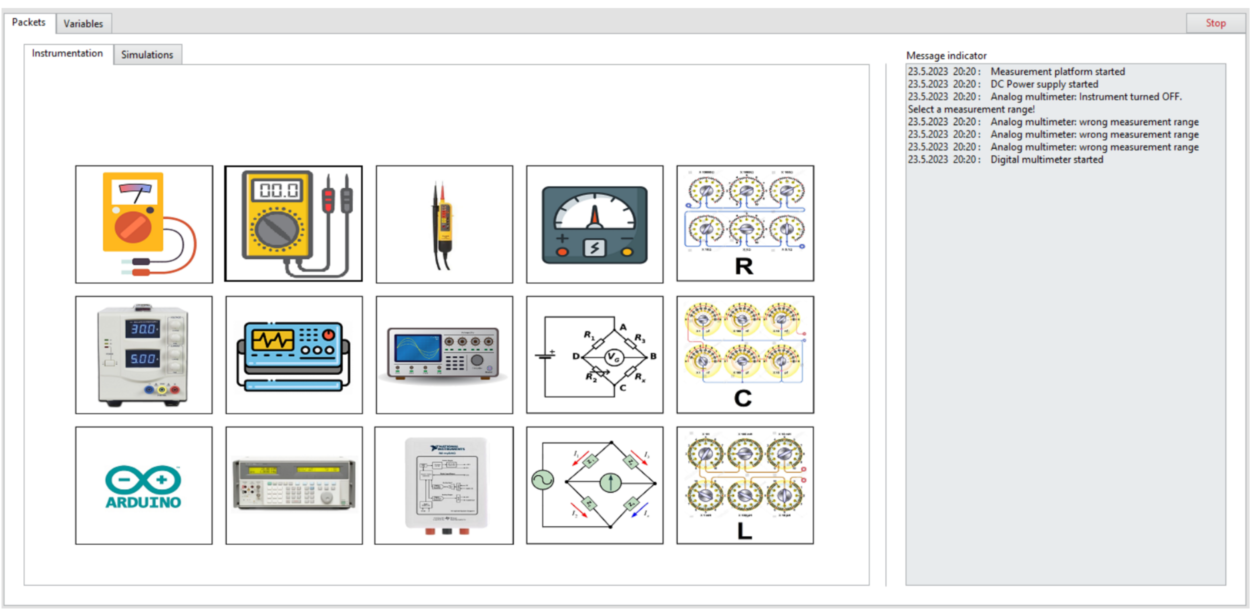


Fig. 1 Front panel of the virtual instrumentation laboratory platform

The RVILP consists of two main components: Instrumentation and simulation. In the Instrumentation section, users can access a comprehensive collection of standard instruments commonly found in engineering laboratories. These virtual instruments are equipped with the ability to communicate with one another, enabling the interfacing of real physical signals. This functionality allows users to replicate and interact with genuine measurement scenarios. On the other hand, the simulation tab provides virtual instruments specifically designed to simulate various instruments or operational principles commonly encountered in the field of measurement science and technology. These simulation tools offer users the opportunity to explore and understand theoretical concepts and experimental setups in a virtual environment. Additionally, the platform offers a variables tab where users can conveniently view, export, or store the signals generated by the global variables. This feature allows for easy access to and management of the data associated with the global variables used throughout the experiments.

The primary objective of the RVILP platform is to create a virtual laboratory environment that replicates real-world experiments, enabling the monitoring of measurement parameters using data acquisition cards through the virtual instrumentation laboratory platform. This concept has broad applicability across various engineering domains since virtual instruments are versatile tools essential for conducting a wide range of measurements. The platform offers hardware support for integrating National Instruments-related hardware or Arduino boards into the experiments. When utilizing Arduino development boards, users need to upload a specific open-source firmware to enable their compatibility with the virtual platform. Once the firmware is uploaded, the Arduino board functions as a standard data acquisition card, capable of reading analog channels or performing read/write operations on digital channels. Moreover, the platform supports popular digital protocols like I2C, SPI, UART, and PWM.

Beyond providing remote access to a virtual laboratory setup, the virtual instrumentation laboratory platform offers several advantages compared to traditional physical laboratory setups. One significant benefit is the ease of sharing and replicating experiments. Users can access the same virtual instruments and setups from anywhere in the world, facilitating collaboration among researchers and enabling students to access laboratory resources regardless of their location. Additionally, the platform serves as a valuable teaching tool to enhance engineering education. By offering a virtual instrumentation laboratory environment that simulates real-world experimentation, it provides students with an interactive and engaging learning experience. Furthermore, students can experiment freely without concerns about damaging physical equipment or consuming expensive resources.

This part of the laboratory manual comprises three laboratory exercises that utilize the virtual instrumentation laboratory platform. The purpose of these exercises is twofold: to establish a proof of concept and to inspire other users to leverage the potential of the platform. To showcase its versatility, the laboratory exercises are implemented in three distinct scenarios:

1. Complete virtual instrumentation utilization,

2. Utilizing virtual measurement instruments in conjunction with a specific hardware setup,

3. Excitation and response measurement employing the Remote Virtual Instrumentation Laboratory Platform

Laboratory experiment 1: Voltmeter accuracy verification (calibration)

To ensure accurate measurements of physical quantities, it is essential to understand the accuracy of the measuring instrument. This characteristics can be obtained from the technical datasheet of the instrument and is typically represented as the maximum error occurring within a specified measurement range. In the case of digital instruments, accuracy is commonly expressed as follows:

$$\Delta X = \pm(A\% + B\% + C),$$

where A% is the error of the reading, B% is the error of the measurement range, and C is the resolution error expressed in digits.

For the analog instruments, the accuracy is expressed through the accuracy class by the following formula:

$$a.c. = \frac{\left|\Delta x_i\right|_{max}}{x_{mr}} \cdot 100,$$

where "a.c." is the accuracy class of the instrument, Δx_i is the maximum absolute error in the measurement range x_{mr}.

Throughout its lifespan, an instrument is subjected to various conditions that can impact its accuracy. Therefore, periodic verification (calibration) becomes necessary to either maintain its existing accuracy or establish a new level of accuracy that best reflects the instrument's current condition. In this particular exercise, students are introduced to the process of verifying voltmeters, which serves as the initial step in the calibration process. Generally, there are three methods available for testing measuring instruments during calibration: the compensation method, the comparison method using a more precise instrument, and the utilization of a specialized calibration device (calibrator). In this exercise, the calibration method employs a virtual calibrator. The process involves measuring the voltage generated by the calibrator using both an analog and digital voltmeter. It is crucial that all measurements with the instrument are conducted within the same measuring range, while the calibrator's measuring range can be adjusted during the process to achieve the most accurate readings. The accuracy of the instrument is then assessed by calculating the verification error. The value obtained through adjustment with the calibrator represents the "true" value, while the measured value corresponds to the reading obtained from the measuring instrument.

In the realm of metrology, it is recognized that the quantitative evaluation of a physical quantity should be complemented with a qualitative description encompassing the unit of measurement and a statement concerning the reliability of the measurement. This statement is known as *measurement uncertainty* and should be based on objective facts derived from the technical or scientific understanding of the measurement process. The concept of measurement uncertainty was established by the ISO/BIMP "Guide to the expression of uncertainty in measurement," commonly referred to as GUM, in 1992. Since then, this concept has gained international acceptance as the foundation for determining measurement uncertainty in metrology. According to the GUM, the total measurement uncertainty (y) is determined by applying the law of propagation of measurement uncertainty, which states:

$$u(y) = \sqrt{u_1^{2}(y) + u_2^{2}(y) + \ ...u_n^{2}(y)},$$

where $u_{12}(y)$ – $u_{n2}(y)$ represents the contribution of each individual input quantity to the total measurement uncertainty of the measurement.

Experimental setup

The experiment setup in this exercise consists of a virtual calibrator and two voltmeters, analog (AVM) and digital (DVM). The simplified electrical circuit of the laboratory exercise is given in Fig.1.

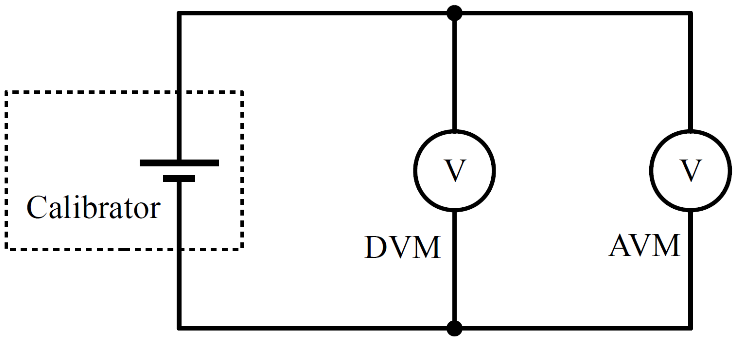


Fig. 2 Experiment setup for verification of analog and digital voltmeters

The measurand in this scenario refers to the direct current (DC) voltage produced by the calibrator, effectively functioning as a DC voltage source. This voltage is measured by both the analog and digital voltmeters, which are connected in parallel and communicate via the same virtual channel, such as CH1. All instruments are activated and controlled using the virtual instrumentation laboratory platform. The front panels of the virtual instruments can be observed in Fig.3.

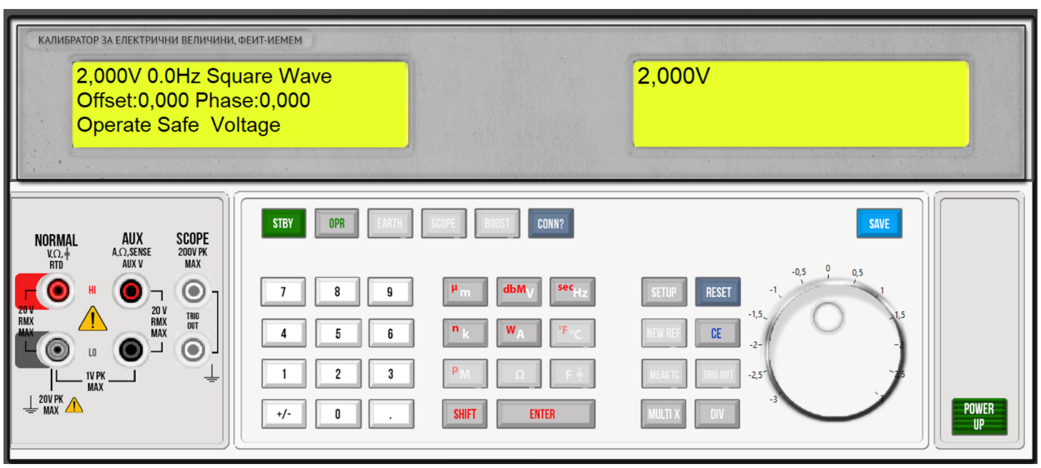
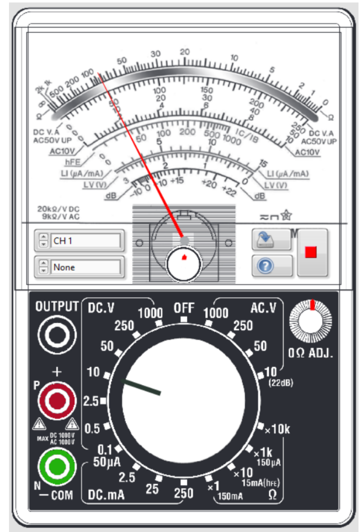


Fig.3.a Virtual calibrator



The readings obtained from both the analog and digital voltmeters are directly proportional to the predetermined voltage set on the virtual calibrator. The accuracy verification process is conducted at multiple points along the measurement range, such as -100%, -80%, ..., 0%, 20%, 40%, ..., and 100%. However, before taking measurements, it is essential to properly configure the voltmeters for DC voltage measurements. This entails ensuring the correct virtual channel is selected (e.g., CH1), specifying the measurement quantity as DC voltage, and choosing the appropriate measurement range. These adjustments are necessary to ensure accurate and reliable readings during the calibration process.

Experimental results

The primary objective of the laboratory exercise is to validate the claimed accuracy provided by the manufacturer. To achieve this, we assess the accuracy of both analog and digital voltmeters within a specified measurement range, following the procedure outlined in the previous chapter. It is crucial to meticulously record the voltmeter readings and appropriately input them into the result tables. Subsequently, we calculate the absolute and relative measurement errors using the virtual calibrator, comparing these values against the maximum allowable error of the voltmeters. The final column in the results tables should reflect the computation of the measurement uncertainty associated with the verification process. Please refer to the following data for detailed technical specifications of all measuring instruments utilized in the verification procedure.

Virtual calibrator DC voltage specifications

Virtual digital voltmeter accuracy specifications

Fill in the following tables with the measurement data obtained from the measurement process. The notations used in the tables are as follows:

U_{cal} – virtual calibrator output voltage

U_{instr} – measured voltage with the instrument

$\Delta U = U_{instr} - U_{cal}$ – verification absolute error

$\delta U = \frac{\Delta U}{U_{cal}} \cdot 100$ – verification relative error

$\pm\ \Delta u_{max}$ – voltmeter accuracy

$\pm u$ – standard absolute measurement uncertainty

Table 1.1 Accuracy verification of digital voltmeter

No.							
1.							
2.							
3.							
4.							
5.							
6.							
7.							
8.							
9.							
10.							

Voltmeter measurement range: U_{mr}=4 V

Plot the obtained results from the verification procedure of the DVM (absolute errors, accuracy limits, calibrator output voltage, and uncertainty bars)

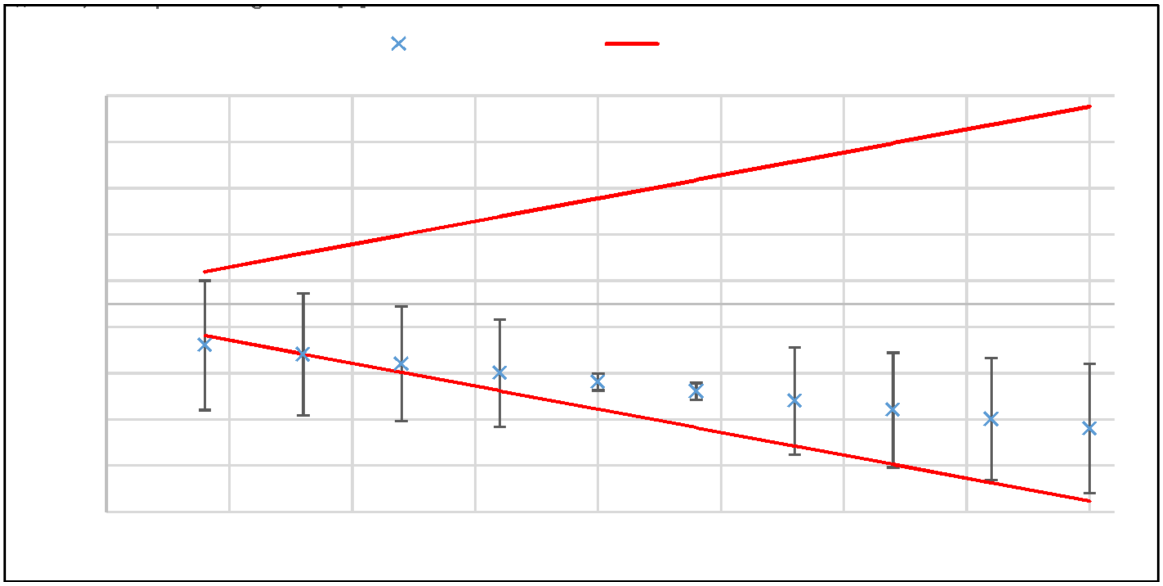


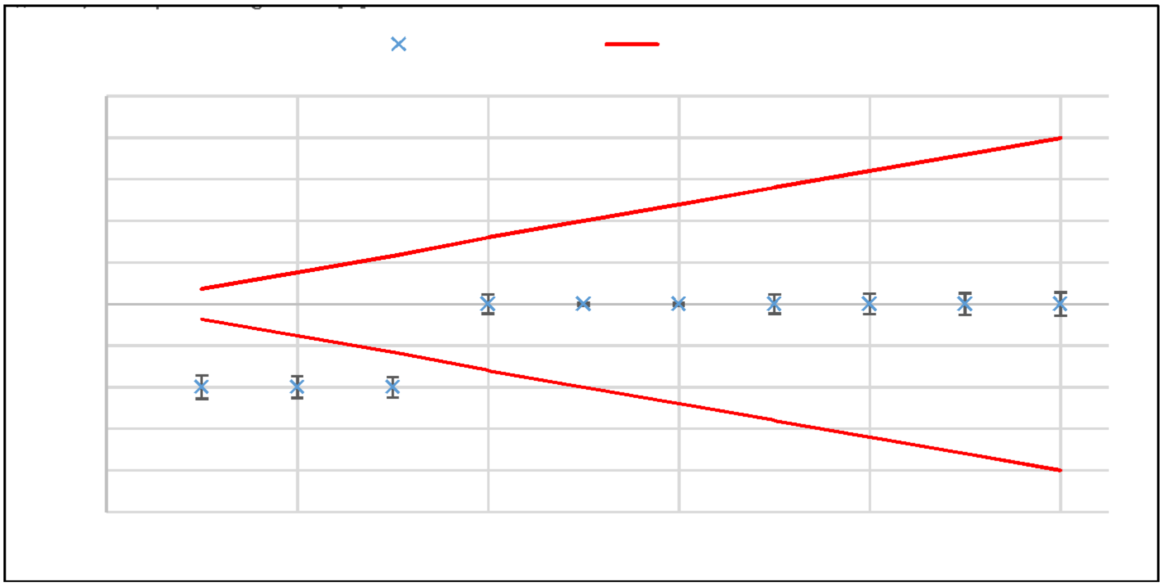
Table 1.2 Accuracy verification of analog voltmeter

No.							
1.							
2.							
3.							
4.							
5.							
6.							
7.							
8.							
9.							
10.							

* the accuracy class of the analog voltmeter is 2

Voltmeter measurement range: U_{mr}=10 V

Plot the obtained results from the verification procedure of the AVM (absolute errors, accuracy limits, calibrator output voltage, and uncertainty bars)



What conclusions can be drawn from the results obtained during the verification of the analog and digital multimeters?

Laboratory experiment 2
Verification of the first Kirchhoff law

The aim of this exercise is confirmation of the first Kirchoff law by simulation and realization of simple electrical circuit. The first Kirchoff law states “*the sum of currents that enter or leave a given junction of the electrical circuit is equal to zero*”. **Junction** is a point where at least three branches of the electrical circuits are joined.

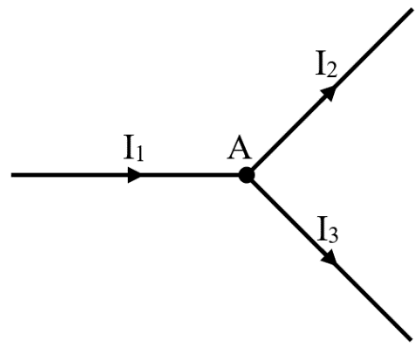


Fig.1 Simplified representation of three branches of electrical circuit forming the junction “A”

The part of the electrical circuit given in the figure above consists of three branches. The branches are joined in the junction A, and the following electrical currents are defined: I1, I2 and I3. The first Kirchoff law for the junction A of the electrical circuit is:

$$(+\ I_1) + \left(-\ I_2\right) + (-\ I_3) = 0$$

In the mathematical formulation of the first Kirchoff law it is assumed than the currents entering the junction (I1 in this case) are positive, while the currents leaving the junction (I2 and I3) are negative. It is clear that the first Kirchoff law also holds in case of opposite current directions. This laboratory exercise demonstrate the exploitation of the RVILP for verification of the first Kirchhoff law in three steps: theoretical calculation, simulation and experimental verification.

We are analyzing a simple electrical circuit formed by three branches (Fig. 2). The first branch consists of a voltage generator E and resistor R_1, while the remaining two branches contain the resistors R_2 and R_3 wired as in the figure below. The task is to determine the electrical currents I_1, I_2 and I_3 and to check the first Kirchoff law for the junction J. In order to solve the electrical circuit, the following parameters are given: E=10 V, R_1=470 Ω, R_2=300 Ω, R_3=200 Ω.

<u>Your task is to calculate the electrical currents in each branch of the circuit by using the recommendations given in this exercise.</u>

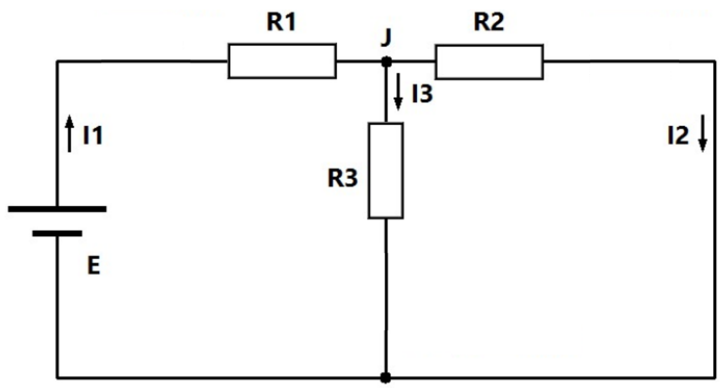


Fig. 2 Simple electrical circuit for verification of the first Kirchoff law

I_1=__________

I_2=__________

I_3=__________

Question: what is the first Kirchoff law for junction J?

Question: is the first Kirchoff law fulfilled? If it is NOT fulfilled, check the calculations and solve the electrical circuit again.

Simulation of ideal electrical circuit

In this part of the exercise we perform a simulation of the ideal electrical circuit given in the previous section. Under "ideal" electrical circuit we assume a circuit where all elements have exact and time invariable parameters. The aim of the simulation is to check the theoretical calculations of the electrical currents I_1, I_2 and I_3. The simulation of the electrical circuit is realized with the RVILP. Run the application for the first Kirchoff law, which is located under the "simulations" tab of the RVILP platform. At this point, a virtual instrument intended for the first Kirchoff law will appear. The simulation of the electrical circuit is realized by selection of the tabulator "Calculation". The front panel of the virtual instrument is given in Fig. 3.

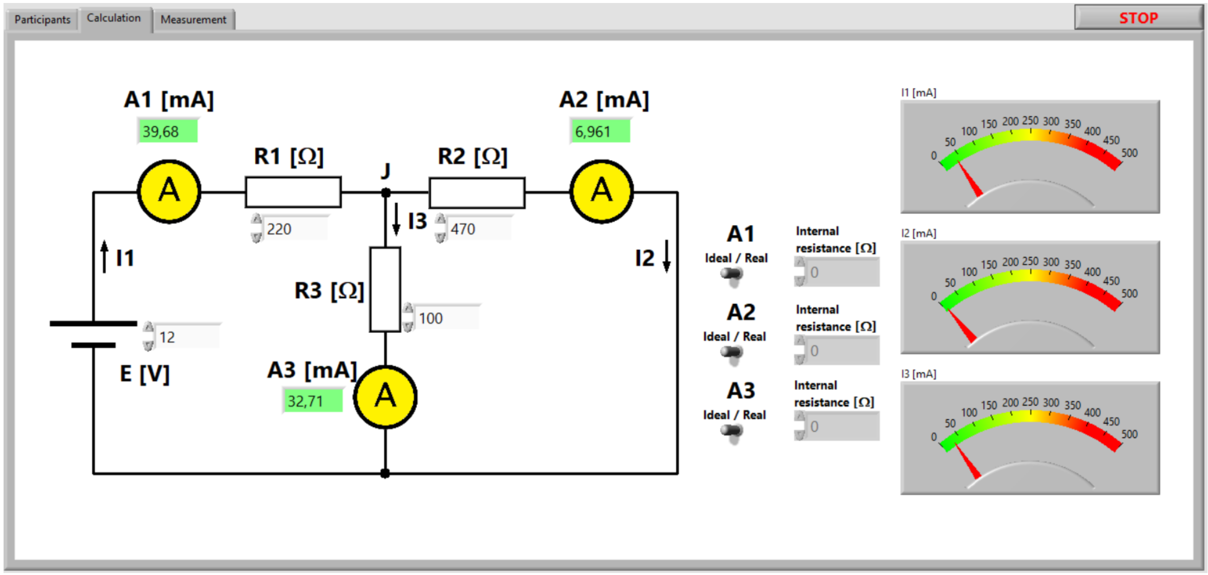


Fig. 3 Front panel of the VI for simulation of the first Kirchoff law

The electrical current is being measured with instrument called amperemeter. In this part of the exercise we assume that the amperemeter is an ideal instruments, i.e. its internal impedance is equal to zero. Hence, the electrical circuit will remain identical if we replace the amperemeters with wires (short circuit). The configuration of the ideal amperemeter (A1, A2 and A3) is realized with the controls "ideal/realistic", by turning them to the "ideal" position.

Each amperemeter is wired in series in the branch whose current is being measured. Hence, the amperemeter A1 is used to measure the electrical current I_1, the amperemeter A2 for the current I_2, and the amperemeter A3 for the current I_3. The measured electrical currents are shown on the indicators A1, A2 and A3.

Your task is to simulate the electrical circuit from section 2 and determine the electrical currents in all branches.

The simulation of the electrical circuit is realized by entering the following parameters: E=10 V, R_1=470 Ω, R_2=300 Ω, R_3=200 Ω. Write the amperemeter readings fir the electrical currents I_1, I_2 and I_3:

$I_1 =$

$I_2 =$

$I_3 =$

Question: are the values from the simulation identical to those obtained by theoretical calculations in the previous section? If they are NOT, check the simulation settings and theoretical calculations all over again.

Question: what is the behavior of the electrical currents I_1, I_2 and I_3 in the electrical circuit if the voltage source decreases (from 10 V to 5 V)?

Experimental setup

This part of the exercise is related to the practical realization of the electrical circuit and performing realistic measurements. The aim is to test the first Kirchoff law once again, but this time in realistic conditions. To perform the experiment we use the experimental board given in Fig. 4.a, and its practical realization in Fig.4.b.

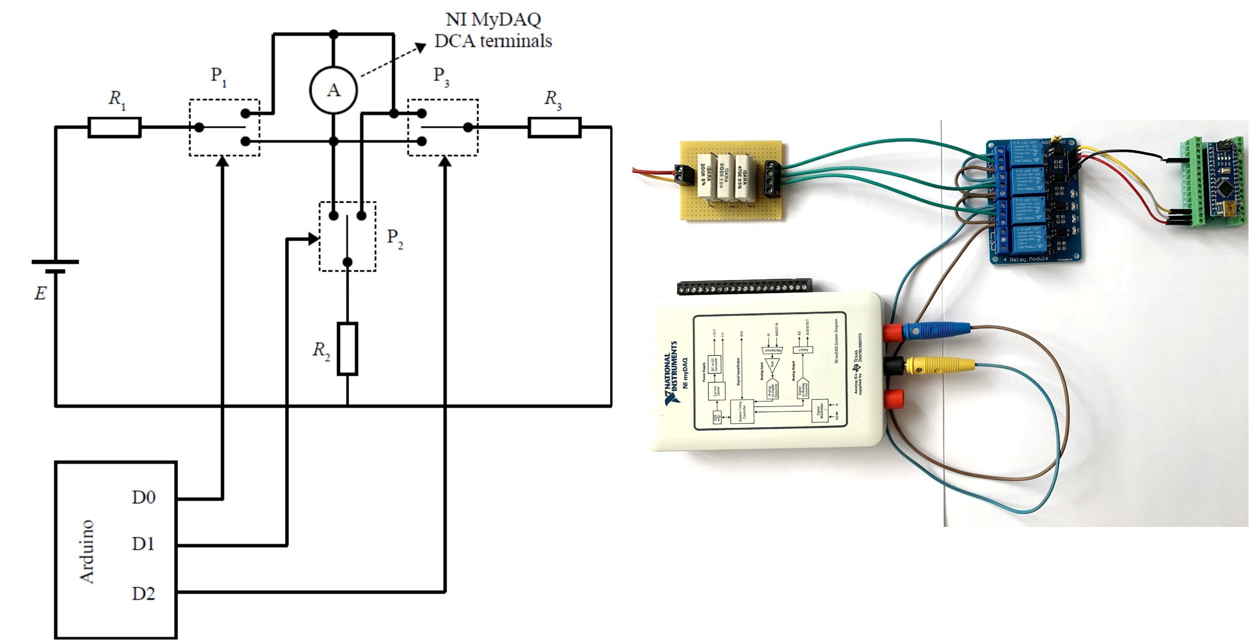


Fig. 4 Experimental verification of the first Kirchoff law, a) Electrical circuit, and b) Practical realization

<u>Your task is to realize the electrical circuit given in Fig. 2 and measure the electrical currents in all branches of the circuit.</u>

The following hardware is used to perform the experiment:

- Experimental board
- Variable DC power supply
- Data Acquisition Card NI-myDAQ
- Arduino board
- Relay modules (P_1-P_3)

We notice that the electrical circuit on the board is identical to those from the previous sections. The resistors R_1=470 Ω, R_2=300 Ω and R_3=200 Ω are integrated into the experimental boar, while the voltage source and the amperemeters are externally connected. Actually, the experiment uses the current input channel of the NI MyDAQ card to measure direct current. The Arduino board controls which current is being measured by appropriate swiching the relay modules (P_1-P_3).

Procedure for realization of the electrical circuit and performing experimental measurements:

1. Note that the DC power supply is already connected to the experimenter board and it is adjusted to 10 V.

2. Activate the tabulator "Measurement" from the virtual instrument. The following front panel appears:

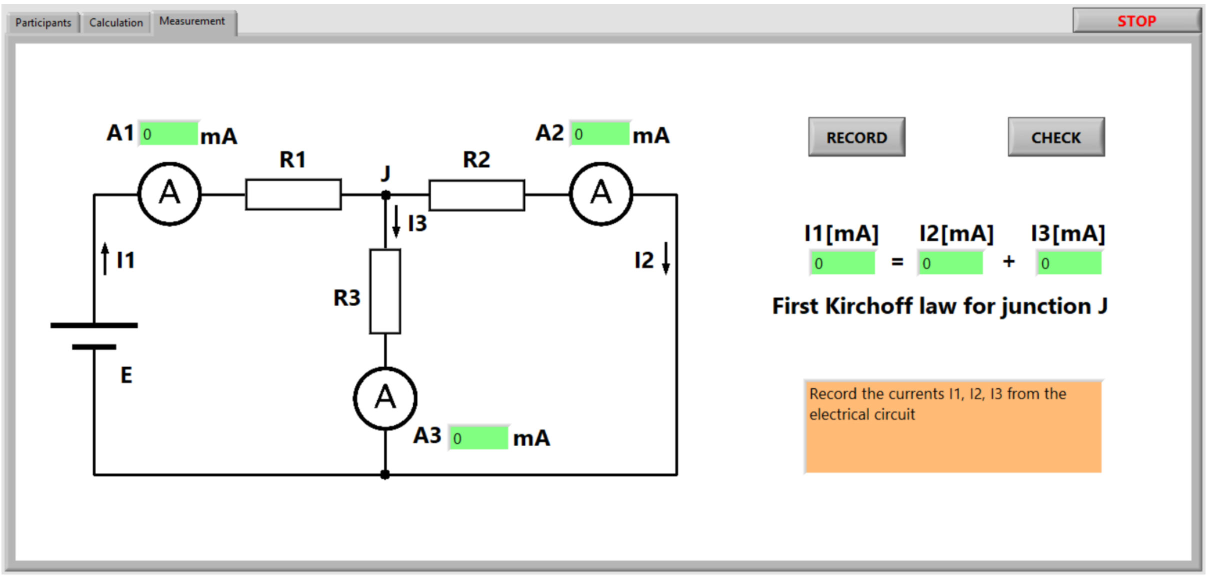


Fig. 5 Front panel of the VI for experimental verification of the first Kirchof law

3. Set the digital output ports of the Arduino board (D0-HIGH, D1-LOW, D2-LOW) through the Arduino VI of the RVILP platform and press the symbol of the amperemeter A1 (the symbol will turn yellow). Then, press the control button "RECORD" on the virtual instrument.

If this step is performed correctly, the measured current in the first branch will appear on the digital indicator I1[mA].

4. Repeat the step 3 for the amperemeters A2 и A3 for measurement of the electrical currents I_2 and I_3.

Write down the measured values for the electrical currents by using the NI-myDAQ instrument:

$I_1 =$

$I_2 =$

$I_3 =$

5. To check the first Kirchoff law for the junction J press the control button "CHECK" on the virtual instrument.

The orange text indicator delivers a text message concerning the first Kirchoff law for the junction J. In case the first Kirchoff law is not fulfilled, the indicators are cleared and the experiment must be repeated again from the step 2.

6. Compare the measurements for the electrical currents with the NI-MYDAQ with the theoretical calculations and the simulations from the previous sections.

Question: do the measured values completely match the results from the theoretical calculations and the simulations?

Note: Examine using realistic instruments (enter the amperemeter internal resistance) in the “simulation” tab. Are the simulation results getting closer to the results from the practical measurements?

Laboratory experiment 3

In this laboratory exercise, we will explore the fundamental principles and practical aspects of measuring the transfer characteristic of a PIN photodiode, a crucial device widely used in optoelectronic applications. Photodiodes are semiconductor devices that convert light into an electrical current. Among the different types of photodiodes, the PIN photodiode stands out due to its unique structure and characteristics. The PIN photodiode consists of three distinct regions: a P-type semiconductor layer sandwiched between two N-type semiconductor layers. The "P" stands for positive, indicating an excess of positive charge carriers, while the "N" represents an excess of negative charge carriers.

When light strikes the depletion region, the region where the P and N layers meet, electron-hole pairs are generated. The electric field within the depletion region separates these charges, creating a photocurrent proportional to the incident light intensity. The transfer characteristic of a PIN photodiode describes the relationship between the output current and the input optical power or light intensity.

In this laboratory exercise, we will explore the experimental techniques and procedures necessary to measure the transfer characteristic of a PIN photodiode when using the signal conditioning curcuit given in Fig. 1. We cover topics regarding the signal conditioning, data acquisition and linear approximation by using the least squares method. Additionally, the students can observe the key parameters and considerations that impact the transfer characteristic, including dark current, and linearity.

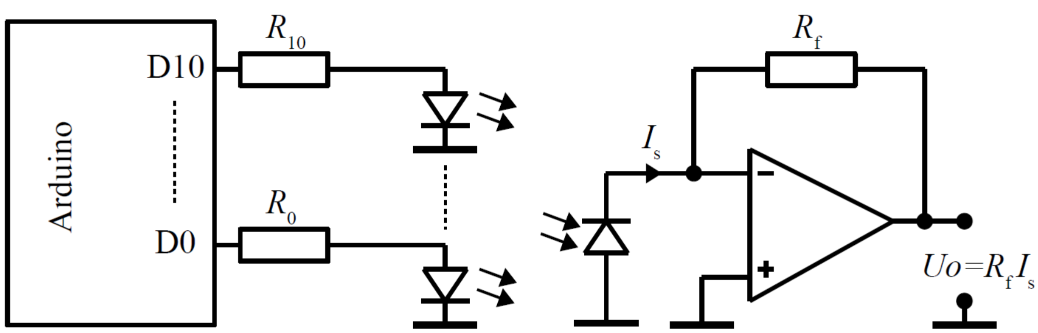


Fig. 1 Experimental setup including the Arduino board, excitation LEDs, PIN photodiode, and signal conditioning circuit

Experimental setup

In order to set up the experimental setup, the following equipment is required:

- Firstly, a particular PIN photodiode is needed in the visible spectrum of the light. This is a type of photodetector that operates by converting light into an electrical current. It will serve as the primary sensor for detecting light in the experiment.

- Next, an Arduino Uno or Nano board is necessary. This microcontroller board will act as a control and data acquisition module, responsible for receiving inputs from the photodiode and controlling the output of the LED diodes. The Arduino board will process the data from the photodiode and perform the required signal conditioning.
- Ten green LED diodes with a wavelength in the middle of the spectral range of the PIN photodiode (approximately 555 nm for visible region) are also required. These LEDs will be used to emit light at a specific wavelength, and particular illumination, which will be detected by the photodiode. The LEDs should be of the same type and specifications to ensure consistency in the experiment.
- To condition the signal from the photodiode, a signal conditioning circuit is needed. This circuit will process the electrical output from the photodiode to make it suitable for further analysis. It involves amplification in order to use the entire measurement range of the Arduino input analog to digital (AD) converters.
- Lastly, a Remote Virtual Instrumentation Platform (RVILP) is required. This platform provides a virtual interface or software that enables remote control and data acquisition from the experimental setup. It allows users to monitor and interact with the Arduino board, photodiode, and other connected devices remotely, providing a convenient way to collect and analyze data.

Experimental Procedure:

Step 1: Setting Up the Arduino and RVILP

Assemble the necessary equipment, including the Arduino board, PIN photodiode, green LED diodes, and signal conditioning circuit. Connect the Arduino board to your computer using a USB cable. Launch the RVILP software on your computer and establish a connection with the Arduino board through the RVILP platform (Fig. 2).

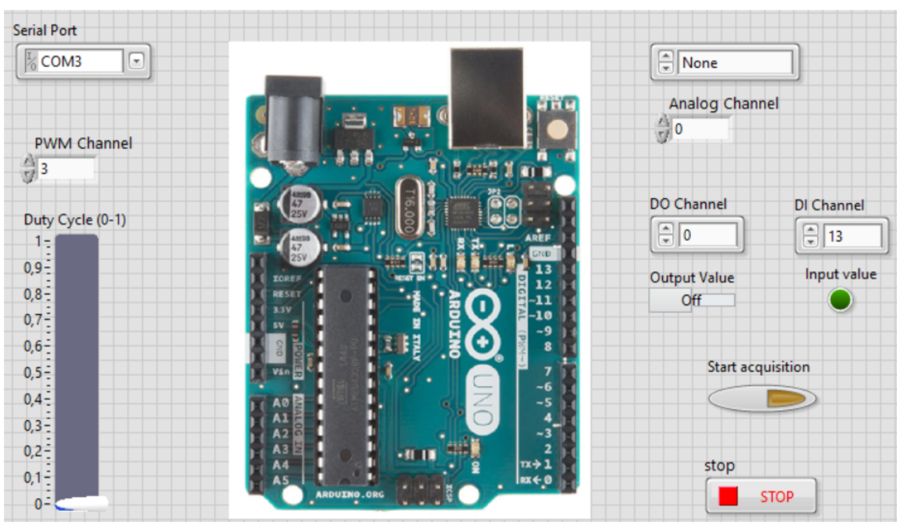


Fig. 2 Front panel of the Arduino virtual instrument embedded into the RVILP platform

Step 2: Configuring the LED Diodes

Connect the green LED diodes to the Arduino board, positioning them at a distance of 5 cm normal to the PIN photodiode. Utilize the RVILP software to control the Arduino board, allowing for the sequential switching on of the LED diodes.

Step 3: Signal Conditioning Circuit

Set up the signal conditioning circuit to ensure accurate measurement of the PIN photodiode's output voltage. Connect the output of the PIN photodiode to the input of the signal conditioning circuit. Then, connect the output of the signal conditioning circuit to one of the analog input ports of the Arduino board (e.g. A0).

Step 4: Conducting the Measurements

Ensure that the PIN photodiode is appropriately positioned and aligned with the LED diodes. Measure the output voltage of the PIN photodiode without any light illumination to determine the dark current. The measurements are performed by using a virtual voltmeter from the RIVLP platform. Use the RVILP software to control the Arduino board, causing the LED diodes to illuminate sequentially. Measure the output voltage of the signal conditioning circuit for each illuminated LED diode. Record the corresponding LED diode number and the measured output voltage in a table. Repeat this process for all ten LED diodes, resulting in ten discrete points for the transfer characteristic.

Experimental results

Table 1.1 Transfer characteristics of the PIN photodiode and signal conditioning circuit

No.	Illumination [%]*	OP amp output voltage [V]
1.	**0**	**0.0**
2.	**10**	**0.21**
3.	**20**	**0.51**
4.	**30**	**0.81**
5.	**40**	**1.12**
6.	**50**	**1.42**
7.	**60**	**1.72**
8.	**70**	**2.03**
9.	**80**	**2.33**
10.	**90**	**2.73**
11.	**100**	**3.03**

* The Illumination is expressed in percent normalized to the total Illumination from all 10 LED diodes

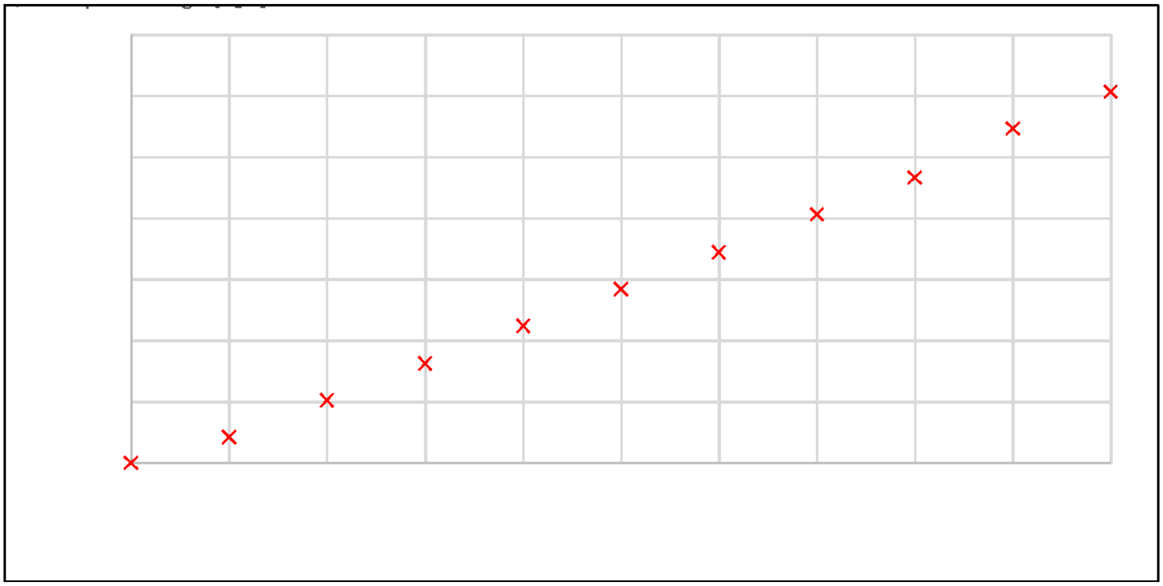


Fig. 3 Transfer characteristics of the PIN photodiode

Least squares approximation

The least squares approximation is a widely used method for finding the best-fitting curve or line that minimizes the overall squared distance between the observed data points and the predicted values from the model. It provides a robust and efficient way to estimate parameters and make predictions based on limited or noisy data.

In this laboratory practicum, we explore the principles and applications of least squares approximation through PIN photodiode hands-on experiments. As input parameters we are using the experimental results obtained from the measurements (given in Table 1.1 and Fig. 3), whereas for the least squares approximation we are using a simulation virtual instrument from the RVILP. The virtual instruments and the obtained linear approximation coefficients are given in Fig. 4.

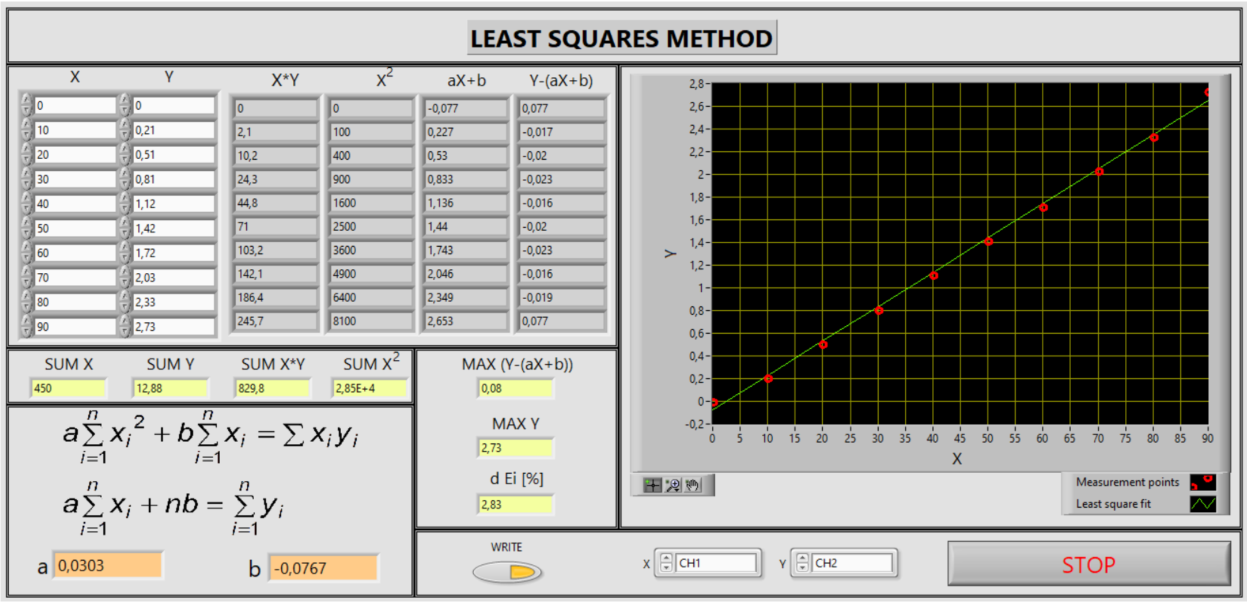


Fig. 4 Virtual instrument for least squares approximation by using linear function