AN DIGITAL TRANSFORMATION ISSUE IN PHYSICS LABORATORY EXPERIMENTS AT THE UNIVERSITY

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Abstract: This paper presents the design of a specialized measuring device for Physics laboratory experiments at the university level. The device allows users to measure voltage and current with high accuracy and provides capabilities for storing and processing measurement data in .doc and .xlsx file formats. Additionally, the device can be further developed to support remote laboratory systems over the Internet and other IoT-based models.

Keywords: Measuring device, Physics experiments, IoT models....

I. INTRODUCTION

In the era of digital technology, optimizing the measurement of parameters such as voltage and current in Physics laboratory experiments has become an essential demand. The integration of measurement devices with digital systems not only enhances accuracy but also helps students improve their data analysis and processing skills in university-level Physics experiments.

In traditional measurements, devices such as voltmeters, ammeters, or oscilloscopes are commonly used. However, these methods have limitations:

- Limited accuracy: Errors due to user mistakes or device shortcomings can affect the results.

- Difficult data integration: Manual recording or reading values consumes significant time.

- Limited analysis capabilities: Data is challenging to analyze quickly and in detail.

Applying digitization in Physics experiments brings many benefits:

- Enhanced accuracy: Modern devices equipped with integrated microcontrollers and high-resolution ADCs (10-24 bits) allow for significantly improved measurements and sampling compared to previous discrete components.

- Automated data recording: Data is saved directly to a computer or the cloud, facilitating analysis.

- Real-time visualization and analysis: Charts and reports can be created instantly.

- Increased flexibility: Students can select parameters such as measurement range or sampling rate to suit their experimental needs.

II. RESEARCH CONTENT

A. Selecting the Model for the Measuring Device

Physics laboratory experiments at the university level (Physics 1 & 2) often require measuring DC voltages. However, certain experiments necessitate measuring rapidly fluctuating AC voltages, such as the voltage across the capacitor plates when studying the charge and discharge process in the following experiment [1].

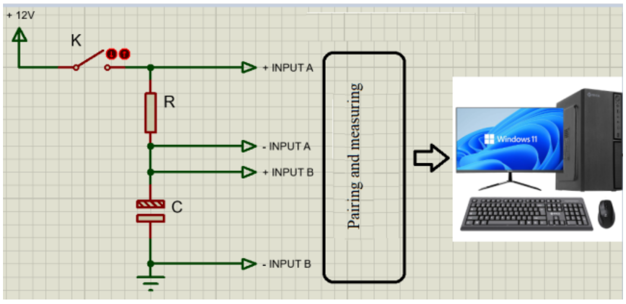

Figure 1. Diagram for observing variable electric fields

In this setup, we need to measure the changing voltages across the capacitor C and resistor R when switch K is closed. Both voltages fluctuate rapidly and cannot be measured using conventional devices. Furthermore, when using two probes A and B, attention must be given to their polarity and physical isolation. Based on these specific requirements, we designed a measuring device model with two isolated probes as shown below:

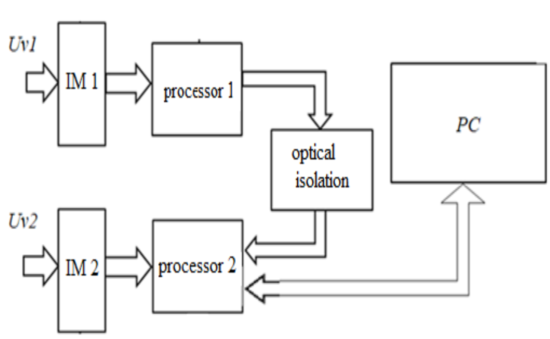

Figure 2. Schematic of the isolated dual-input voltage measurement circuit

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The use of an optically isolated data transmission module ensures the physical isolation of potentials at the measurement points, preventing interference with the circuit's experimental results.

When using an ADC circuit to measure voltages at different ranges, nonlinear correction functions must be applied to adjust the measured results. One simple function for correcting nonlinearity is a quadratic function, where the actual voltage is calculated as:

$$V = a * V^2_{measured} + b * V_{measured} + c$$

Here, a, b, and c are correction coefficients obtained through real-world calibration, and $V_{measured}$ is the value measured by the microcontroller's ADC.

B. Implementation Steps

1) Collecting Calibration Data:

Provide reference voltages (e.g., 1V, 2V, 3V) to the ADC input. Record the ADC's measured values corresponding to each reference value (e.g., 0.98V, 2.05V, 3.12V)

2) Building the Correction Equation:

Use calibration data to determine the coefficients a, b, and c via the Least Squares method or tools like Excel, Python, or MATLAB.

3) Applying the Equation in Arduino:

After determining the coefficients, implement the correction function in the Arduino program to convert ADC values to actual voltages.

Arduino code example:

```
float calibrateVoltage (float measuredVoltage) {
  float a = 0.01;
  float b = 0.95;
  float c = 0.05;
  return a * measuredVoltage * measuredVoltage + b
* measuredVoltage + c;
}
void setup() {
  Serial.begin(9600);
}
void loop() {
  int adcValue = analogRead(A0);
  float measuredVoltage = adcValue * (5.0 / 1023.0);
// Chuyển đổi giá trị ADC sang điện áp
  float realVoltage =
calibrateVoltage(measuredVoltage); // Hiệu chỉnh
  Serial.print("Voltage: ");
  Serial.println(realVoltage);
  delay(1000);
}
```

4) Using Python to Determine Coefficients a, b, c:

```
import numpy as np
# Dữ liệu hiệu chuẩn
V_measured = np.array([0.98, 2.05, 3.12])
V_real = np.array([1.00, 2.00, 3.00])
# Xác định hệ số hàm bậc 2
coefficients = np.polyfit(V_measured, V_real, 2)
a, b, c = coefficients
        print(f"Hệ số: a = {a}, b = {b}, c = {c}")
```

Results: a=0.01, b=0.95, c=0.05

5) Hardware and software introduction

Based on the schematic design and analysis of hardware resources and software tools, the author designed a measuring device using components such as the Arduino UNO microcontroller, 6N137 optical isolators, and Python-based interfacing software.

6) IC 6N137

Description The 6N137 optocouplers consist of an 850 nm AlGaAS LED, optically coupled to a very high speed integrated photo-detector logic gate with a strobable output. This output features an open collector, there by permitting wired OR outputs. The switching parameters are guaranteed over the temperature range of -40°C to +85°C. A maximum input signal of 5mA will provide a minimum output sink current of 13mA (fan out of 8). Applications • Line receivers • Telecommunication equipment • Feedback loop in switch-mode power supplies • Home appliances • High speed logic ground isolation.

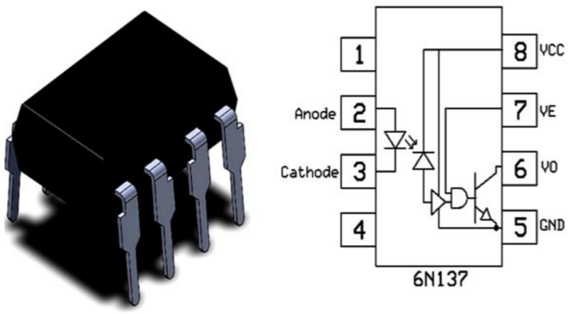

Figure 3 6N137 structure

7) Adruino UNO & ATMEGA 32

Arduino Uno is a microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter. The basic parameters of this device are presented in Table 1.

Figure 4 Adruino-UNO

Table 1: Basic Parameters

Emitter Characteristics

Symbol	*Parameters*	*Test Conditions*	*Min*	*Typ*	*Max*	*Units*	*Notes*
V_F	Forward voltage	IF = 10mA	-	1.4	1.6	V	
V_R	Reverse Voltage	IR = 10μA	5.0	-	-	V	
$\Delta V_F/\Delta T_A$	Temperature coefficient of forward voltage	IF =10mA	-	-1.8	-	mV/℃	

Detector Characteristics

Symbol	*Parameters*	*Test Conditions*	*Min*	*Typ*	*Max*	*Units*	*Notes*
I_{CCH}	Logic High Supply Current	I_F=0mA, V_E=0.5V, V_{CC}=5.5V	-	6.5	10	mA	
I_{CCL}	Logic Low Supply Current	I_F=10mA, V_E=0.5V, V_{CC}=5.5V	-	8.8	13	mA	
V_{EH}	High Level Enable Voltage	I_F=10mA, V_{CC}=5.5V	2.0	-	-	V	
V_{EL}	Low Level Enable Voltage	I_F=10mA, V_{CC}=5.5V	-	-	0.8	V	
I_{EH}	High Level Enable Current	V_E=2.0V, V_{CC}=5.5V	-	-0.53	-1.6	mA	
I_{EL}	Low Level Enable Current	V_E=0.5V, V_{CC}=5.5V	-	-0.75	-1.6	mA	

Transfer Characteristics

Symbol	*Parameters*	*Test Conditions*	*Min*	*Typ*	*Max*	*Units*	*Notes*
I_{FT}	Input Threshold Current	V_{CC}=5.5V, V_O=0.6V, V_E=2.0V, I_O=13mA	-	2.5	5	mA	
I_{OH}	Logic High Output Current	I_F=250μA, V_O=V_{CC}=5.5V, V_E =2.0V	-	2.0	100	μA	
V_{OL}	Low Level Output Voltage	I_F=5mA, V_{CC}=5.5V, V_E=2.0V, I_O=13mA	-	0.35	0.6	V	

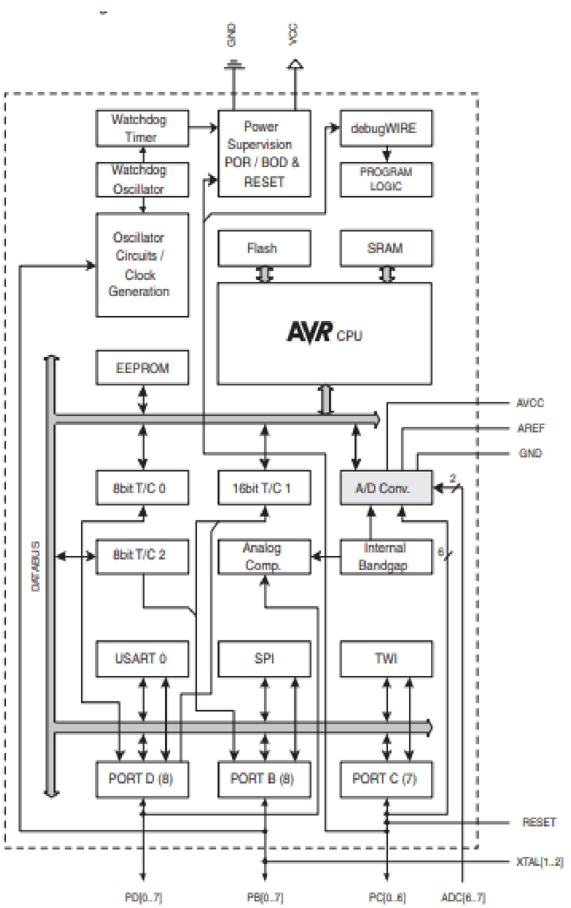

Figure 5 ATMEGA 32 structure

Features

- High Performance, Low Power AVR® 8-Bit Microcontroller
- Advanced RISC Architecture
  - 131 Powerful Instructions – Most Single Clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 16 MIPS Throughput at 16 MHz
  - On-chip 2-cycle Multiplier
- High Endurance Non-volatile Memory Segments
  - 32K Bytes of In-System Self-Programmable Flash progam memory
  - 1K Bytes EEPROM
  - 2K Bytes Internal SRAM
  - Write/Erase Cycles: 10,000 Flash/100,000 EEPROM
  - Optional Boot Code Section with Independent Lock Bits
    - In-System Programming by On-chip Boot Program
    - True Read-While-Write Operation
  - Programming Lock for Software Security
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescaler and Compare Mode
  - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Six PWM Channels
  - 8-channel 10-bit ADC in TQFP and QFN/MLF package
    - Temperature Measurement
  - Programmable Serial USART
  - Master/Slave SPI Serial Interface
  - Byte-oriented 2-wire Serial Interface (Philips I²C compatible)
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
  - Interrupt and Wake-up on Pin Change
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated Oscillator
  - External and Internal Interrupt Sources
  - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and Extended Standby
- I/O and Packages
  - 23 Programmable I/O Lines
  - 32-lead TQFP, and 32-pad QFN/MLF
- Operating Voltage:
  - 2.7V - 5.5V for ATmega328P

Figure 6 Parameters of ATMEGA 32

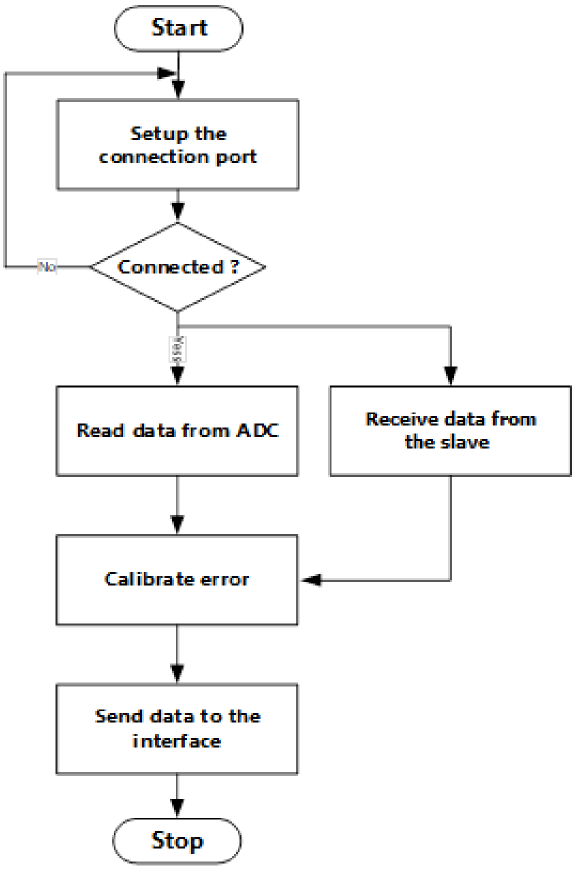

Figure 7 VL Algorithm flowchart

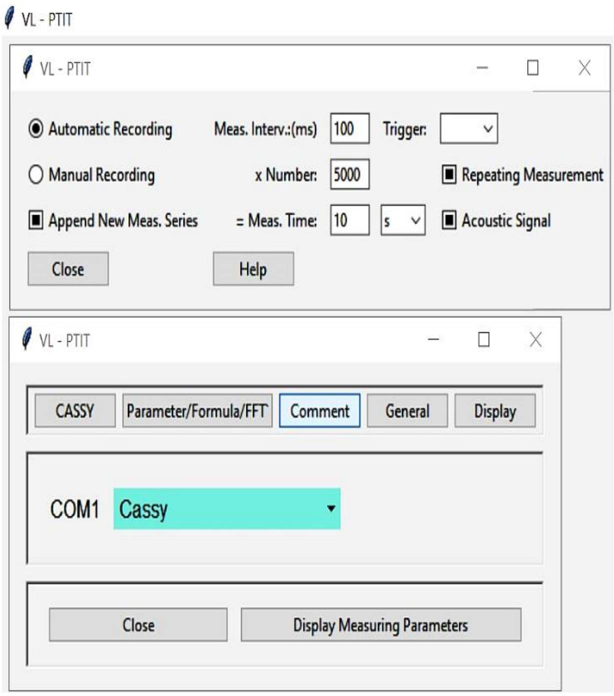

Figure 8 VL software interface

Figure 7 is the algorithm flowchart for the hardware communication software. In this flowchart, data is collected from two measurement inputs: one from the ADC on the Arduino (Master) and the other sent from the Arduino (Slave). The data is then gathered and calibrated for errors before being sent to the interface.

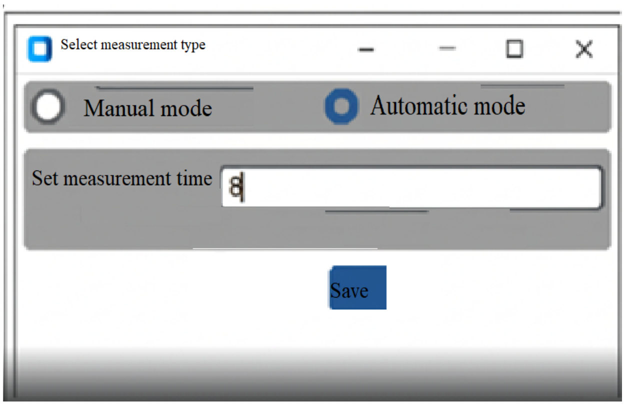

Figure 9 Select measurement type

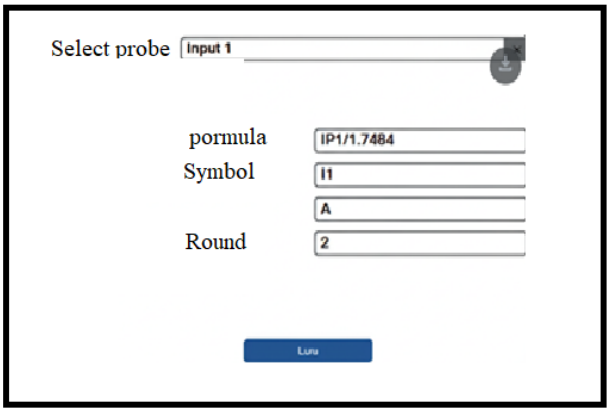

Figure 10 Probe installation

C. *Results and Related Issues*

The measurement data from both probes are automatically plotted by the software (after closing switch K and pressing F9 to start measurement). The graph above illustrates the results.

Table 2: Results measured with ADC

Mutimeter		ADC	
A	V	A	V
0.211	3.27	0.213	3.27
0.415	6.49	0.417	6.41
0.606	9.53	0.61	9.44
0.784	12.28	0.79	12.4
0.214	3.29	0.208	3.24
0.421	6.4	0.408	6.35
0.611	9.39	0.599	9.36
0.776	12.21	0.774	12.17
0.21	3.27	0.208	3.26
0.41	6.47	0.408	6.38
0.6	9.44	0.598	9.32
0.784	12.3	0.765	12.15
0.21	3.17	0.199	3.13
0.41	6.35	0.398	6.26
0.603	9.21	0.584	9.18
0.786	12.02	0.761	12.03

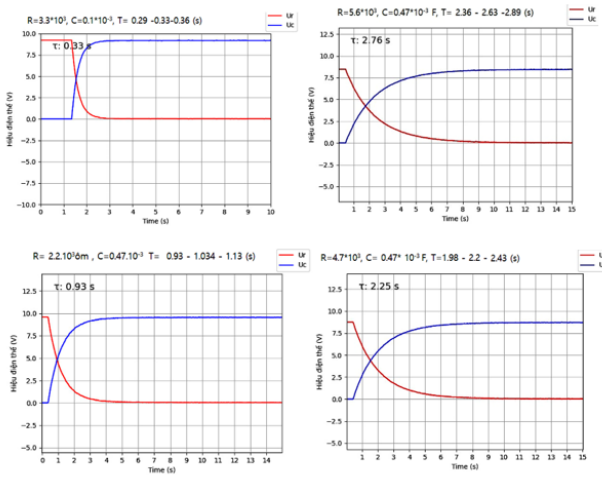

Figure 11 measure and graph

However, the measured results need to be taken at different pairs of R and C values in order to calibrate the calculation of the charging and discharging constants of the capacitor C

Measure the capacitance charging of the capacitor.

Measure the capacitance discharging of the capacitor.

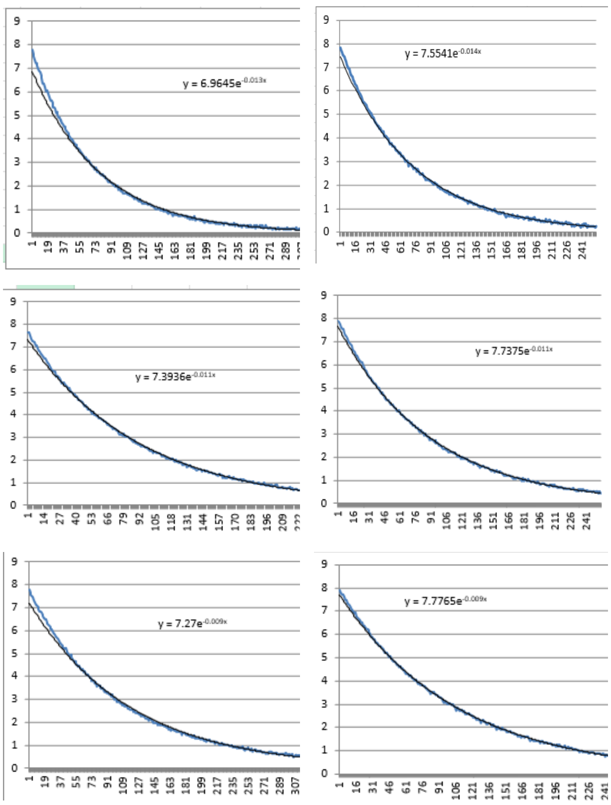

Figure 12 shows the time constants for charging and discharging a capacitor with different values.

II. CONCLUSION

This paper presents research on the design of a voltage and current measuring device for university Physics experiments, specifically for Physics 1 & 2. The measuring device allows direct connection to a computer through specialized software developed for this measurement task, enabling students to store and process data directly during the experiment.

VẤN ĐỀ CHUYỂN ĐỔI SỐ TRONG CÁC BÀI THÍ NGHIỆM VẬT LÝ Ở TRƯỜNG ĐẠI HỌC

Tóm tắt: Bài báo này trình bày thiết kế một thiết bị đo chuyên dụng cho các thí nghiệm phòng thí nghiệm Vật lý ở cấp đại học. Thiết bị cho phép người dùng đo điện áp và dòng điện với độ chính xác cao, đồng thời cung cấp khả năng lưu trữ và xử lý dữ liệu đo dưới định dạng tệp .doc và .xlsx. Ngoài ra, thiết bị còn có thể được phát triển thêm để hỗ trợ hệ thống phòng thí nghiệm từ xa qua Internet và các mô hình IoT khác.

Từ khoá: Thiết bị đo, thí nghiệm Vật lý, mô hình IoT

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