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Real-Time Visualization of Capacitor Charging and Discharging via Separate Paths: Arduino UNO and Optocoupler Relay Automation

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Abstract
This paper introduces a Virtual Instrument (VI) created in the LabVIEW platform with LINX toolkit developing an automated cost-effective data acquisition system using Arduino UNO for real-time visualization of Capacitor charging and discharging through different paths. Optocoupler relays have been used to automate the path selection. Capacitor charging and discharging are fundamental processes in electronics, physics and engineering exhibiting transient phenomena with practical applications. These processes are characterized by transient phenomena such as exponential voltage changes and time constants, governed by the capacitance and resistance in the circuit. This paper mainly focuses on real-time visualization and data capture of the time-dependent behavior of charging a capacitor through one resistor and discharging through another resistance and extracting time-constant parameters for different paths in a cost effective approach. The time-constant values for charging and discharging have been extracted from Real-time plots and compared with its standard values and those are in strong agreement indicating the efficacy of the developed method. It highlights the application of Arduino and LabVIEW in studying transient phenomena in real-time scenarios. Real-time visualization and Understanding these phenomena is crucial in various practical fields, from energy storage systems to signal processing.
Keywords: *Transient Phenomena, Arduino UNO, LabVIEW LINX, Optocoupler Relay*

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I. INTRODUCTION

Microcontroller technology tools have been effectively employed in science and engineering classrooms to enhance students' understanding and problem-solving abilities [4]. However, helping students grasp concepts and comprehend the potential of technology can be challenging. Arduino, an open-source microcontroller, [1] has found diverse applications across various technology fields. In physics education, Arduino platforms have facilitated the creation of experimental setups for topics such as simple harmonic oscillations, momentum in one dimension, and speed of sound in air, among others [5] [6] [7]. One notable integration involves using Arduino-LabVIEW™ via the LINX toolkit [2] to study transient phenomena in RC circuits, offering real-time data visualization [8][9]. Transient phenomena are a quick process and very difficult to record manually. Traditionally, experiments involving voltmeters and stopwatches can be laborious and prone to errors. This is where technology proves valuable. To address this, the VI has been developed using Arduino and a LabVIEW interface, allowing experiments on capacitor charging and discharging through separate paths to elucidate theories of Transient phenomena of RC circuits. The specific charging and discharging time plays a crucial role for a wide array of applications including scenarios like Camera Flash Units, Industrial Automation, Uninterruptible Power Supplies (UPS), Motor Starters, Electric Vehicles and more.

This paper focuses on the time-dependent behavior of charging a capacitor through one resistor and discharging through another resistance and extracting time-constant parameters for different paths. It highlights the application of Arduino and LabVIEW in studying transient phenomena in real-time scenarios. This comprehensive VI offers a valuable tool for researchers and engineers in the field of energy storage, signal analysis and many, providing an efficient and user-friendly solution for visualizing and analyzing the practical applications related to transient phenomena.

II. THEORETICAL BACKGROUND

Capacitors are fundamental electrical components that store and release electrical energy. They play a crucial role in a wide range of electronic circuits, from power supplies to timing circuits. Understanding the processes of capacitor charging and discharging is essential for anyone delving into electronics. When a voltage is applied across a capacitor, it begins to charge. This charging process involves the accumulation of electric charge on the capacitor's plates, resulting in the buildup of potential energy. The rate at which a capacitor charges is determined by its capacitance (C) and the resistance (R) of the circuit it's connected to. Mathematically, the charging process of a capacitor can be described by the equation:

$$V(t) = V_{max} \times (1 - e^{-\frac{t}{R \cdot C}})$$

where V(t) is the voltage across the capacitor at time t ; Vmax is the maximum voltage the capacitor can reach (equal to the source voltage). R is the resistance in the circuit. C is the capacitance of the capacitor and t is the time elapsed.

On the other hand, when a charged capacitor is disconnected from its power source and connected to a discharge path (usually through a resistor), it begins to discharge. During this process, the stored energy in the capacitor gets released, and the voltage across the capacitor decreases over time. The discharge process of a capacitor can be mathematically represented as:

$$V(t) = V_{max} \times e^{-\frac{t}{R \cdot C}}$$

V(t) is the voltage across the capacitor at time t. V_{max} is the initial voltage across the capacitor at the start of discharging. R is the resistance in the discharge circuit. C is the capacitance of the capacitor and t is the time elapsed.

In both charging and discharging equations, the time constant $\tau = R \cdot C$ plays a crucial role. It determines the rate at which the capacitor's voltage changes. A smaller time constant results in faster voltage changes, while a larger time constant leads to slower changes. Studying the processes of capacitor charging and discharging, along with these mathematical equations, enables engineers and enthusiasts to design and analyze various electronic circuits and systems with capacitors, contributing to the advancement of modern technology.

III. EXPERIMENTAL SETUP

The circuit configuration is depicted in **Figure 1** through a Fritzing diagram [3].

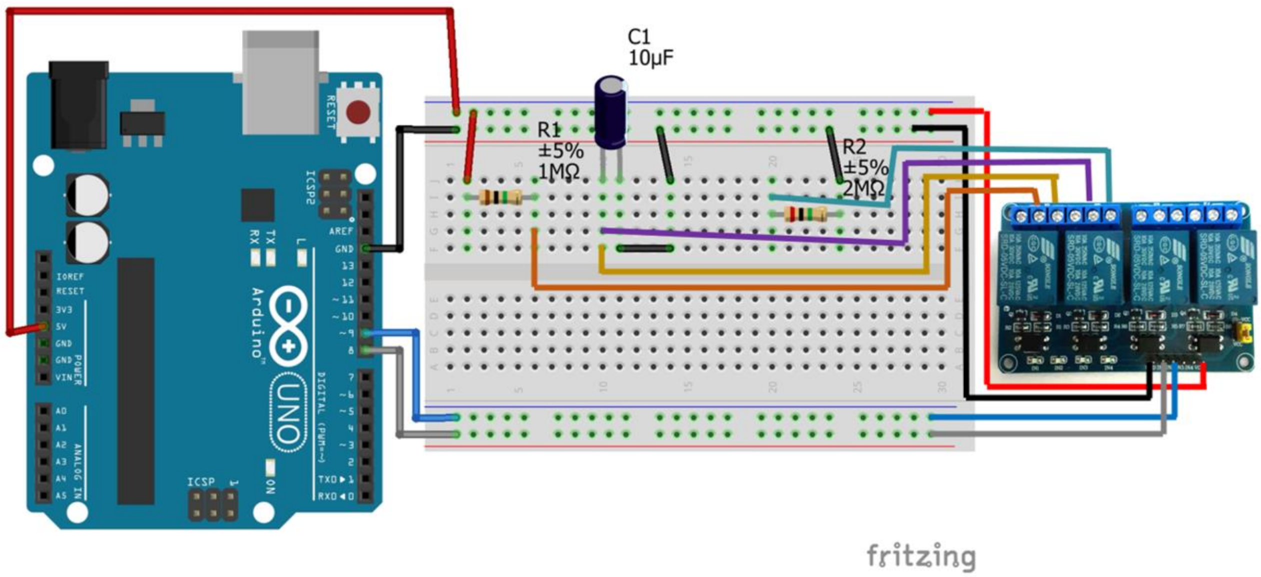

Figure 1 : Fritzing diagram of the circuit for Automated Real-time visualization of Charging and Discharging of a Capacitor in separate paths using Arduino UNO and Relays

This circuit serves as the external setup, under the regulation of an Arduino UNO through the LabVIEW platform. No Arduino IDE is required. The integration between the Arduino and LabVIEW employs via the LINX toolkit, a Hobbyist firmware wizard and then the LINX toolkit must be configured with proper Arduino version and Connecting Port. **Figure 2** outlines the schematic representation of the data flow within this experimental setup.

Figure 2 : Data Transmission and Reception Across Setup Components

To address the core objective of this study, a charging route is established using a 1.1 $M\Omega$ resistor (R1) in conjunction with a commercially available standard capacitor $C = 10.1\ \mu F$. Simultaneously, an independent discharging route is configured using 2.1 $M\Omega$ along with the same capacitor C. The selection between the charging and discharging pathways is automated via two optocoupler relays, controlled by LabVIEW code through Arduino manipulation.

The experimental exploration involves the manipulation of capacitor values and adjustment of charging and discharging durations. This allows for a comprehensive comparative analysis against established reference measurement values.

IV. FINDINGS

Transient phenomena within RC circuits have been effectively realized through practical implementation. The process involves the automated and real-time execution of capacitor charging, utilizing a specific resistance ($R_1 = 1.1\ M\Omega$), and capacitor discharging, facilitated by a distinct resistance ($R_2 = 2.1\ M\Omega$). The charging duration has been established for a period of 50 seconds, followed by a subsequent discharge phase lasting an additional 50 seconds. The temporal dynamics are indicated via a cursor, precisely marking the time-constant parameters for both the charging and discharging routes.

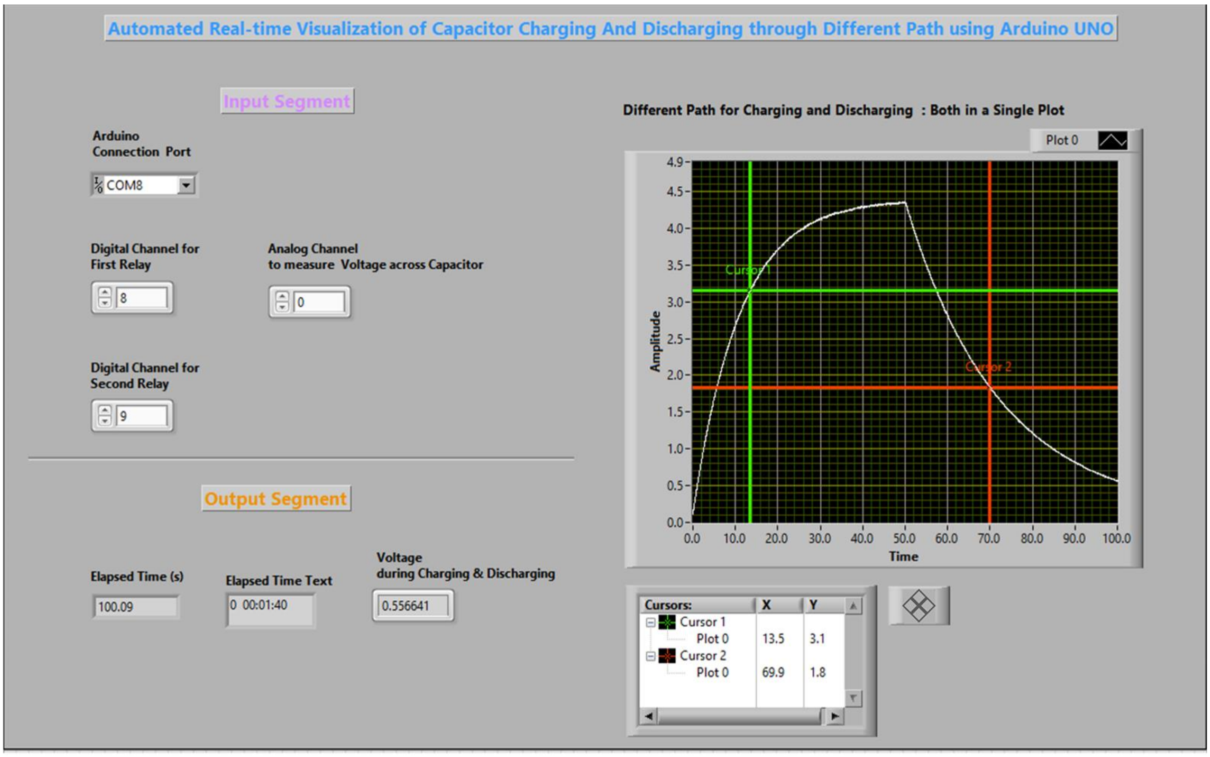

Figure 3: Front Panel of LabVIEW code for Data Input and real-time charging discharging plot

For the charging trajectory, the time constant (τ_1) is approximately 13.5 seconds, demonstrating remarkable proximity to the theoretically anticipated value of 11.1 seconds. Similarly, the discharging route exhibits a time constant (τ_2) of approximately 19.9 seconds, closely aligning with the theoretically projected value of 21.2 seconds.

V. CONCLUSION

In conclusion, the successful implementation of distinct paths for capacitor charging and discharging has been achieved. The LabVIEW code provides the versatility to configure either shorter charging and longer discharging times, or vice versa. The calculated time constants for each pathway closely align with their corresponding theoretical values. By tailoring specific charging and discharging durations, these applications can benefit from improved performance and enhanced efficiency. This study demonstrates an automated, real-time realization of capacitor charging and discharging through divergent routes, utilizing an Arduino-based data acquisition system in a cost-effective manner.

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