Numerical Method and Laboratory Experiment of RC Circuit using Raspberry Pi Microprocessor and Python Interface

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Abstract. RC circuit is the basic physics experiment show the charging and discharging on capacitor electronic component. In this paper, we have investigated the numerical simulation from the mathematical model of charging and discharging of capacitor, also we developed experimentally RC circuit using Raspberry Pi single board microprocessor and make interfaces using Python software. The benefit of this system that all of them was open Source and can help the physics experiment easily at the laboratory. To get data acquisition from RC circuit we used IC MCP3008 which have converted an analog to digital data. The experimental result showed the best agreement with the numerical simulation result.

1. Introduction

Physics experiment is an interesting field that always pushing advance in instrumentation and acquisition system. One of the physics experiment is investigating about charging and discharging of the capacitor through a resistor for the study of electricity [1].

RC Circuit can be modeled by Runge-Kutta Ordinary Differential Equations (ODEs). This numerical method can be used to obtain the approximation solution of RC Circuit. Some numerical method can be used to show ODEs system such as; Euler's method [2] and Runge-Kutta’s method [3] of different orders.

The classical procedure of experiment is done using stopwatch and voltmeter, the procedure probably the human error occurs. Recently, Calin Galeriu, et al [4] and Pareria [5] have used Arduino microcontroller to investigate the RC Circuit. Other microcontroller systems which same work like Arduino is Raspberry Pi. Different from Arduino, the developer of Raspberry Pi build a mini computer processor (microprocessor/microcomputer) integrate with the control for the electronic project [6]. Some researches using Raspberry Pi to build an apparatus experiment laboratory, such as; robot (e.g., [7], [8]), motor dc [9], thermocouple [10], hydrostatic [11], pulse generator [12], astronomy [13], special relativity [14], and other.

In this research will be described a numerical simulation of RC Circuit using Runge-Kutta 4 Order (RK4) method compared with the exact solution. We will validate RC Circuit experimentally. The system in this research will use Raspberry Pi to investigate the charging and discharging process of RC Circuit. The purpose of this research is to build an effective low cost experimental physics of RC Circuit.
The paper is organized as follows. In section 2, described a basic theory of RC Circuit. In section 3, describe a numerical simulation using Python software. In section 4, hardware design of RC Circuit described the works of the system in detail. In section 5, described the experimental results. Finally, in Section 6, the concluding remarks are given.

2. Basic Theory of RC Circuit

RC is a circuit which contains a series combination by a resistor (R) and a capacitor (C) component and connected to DC voltage [15]. RC circuit contains two processes they are “Charging” and “Discharging”, will describe below:

2.1 Charging

In this case, assume that capacitor initially not have a charge. When the switch turns on at \( t = 0 \), the charge will flow into the resistor then fill the capacitor. In Kirchhoff’s law we get;

\[
\frac{dq}{dt} = \frac{1}{R} \left( V_0 - \frac{q}{C} \right),
\]

(1)

where \( \frac{dq}{dt} \) is the time rate of change of the charge, \( V_0 \) is the initial voltage, \( C \) is the capacitance, \( R \) is the resistance, and \( q \) is the charge. To determine the time rate of change of the voltage on the capacitor we can substitute \( q = CV \) to equation (1) can be written as;

\[
\frac{dv}{dt} = \frac{1}{RC} \left( V_0 - v \right),
\]

(2)

with \( \frac{dv}{dt} \) the time rate of change of the voltage, \( V_0 \) is the initial voltage and \( v \) is the voltage. If analyze equation (2) we found the exact solution as;

\[
v(t) = v_0 \left( 1 - e^{\frac{-t}{RC}} \right),
\]

(3)

when \( v(t) \) is the time rate of change of the voltage and \( t \) is the time of charging with range \( a \leq t \leq b \). The process of charging capacitor shown as Figure 1.

2.2 Discharging

In this case, the capacitor charge initially \( V_0 = q / C \), while the potential on the resistor is “zero”. After \( t = 0 \), discharge began by the capacitor. Base on Kirchhoff’s law is given by (4),

\[
\frac{q}{C} + R \frac{dq}{dt} = 0,
\]

(4)
where \( q \) is the charge, \( C \) is the capacitance, \( R \) is the resistance, and \( \frac{dq}{dt} \) is the time rate of change of the charge. In discharging case, to determine the time rate of change of the voltage on the capacitor can substitute \( q = Cv \) from equation (4) can be written as (5),

\[
\frac{dv}{dt} = -\frac{v}{RC}, \tag{5}
\]

with \( \frac{dv}{dt} \) is the time rate of change of the voltage and \( v \) is the voltage. If analyze equation (5), will get the exact solution as;

\[
v(t) = v_0 e^{-\frac{t}{RC}}, \tag{6}
\]

where \( v(t) \) is the time rate of change of the voltage, \( v_0 \) is the initial voltage and \( t \) is the time of discharging with range \( a \leq t \leq b \). Discharging capacitor process shown in Figure 2.

![Figure 2. RC Circuit Discharging Process (a) when \( t < 0 \), (b) when \( t > 0 \).](image)

3. Numerical Simulation

In this study, we use Runge-Kutta 4 Order Method (RK4) to simulate a Charging or Discharging of RC Circuit system, because of Runge-Kutta allow the differential solution with minimize the truncation error [3]. To calculate the numerical simulation of RC Circuit used Python software. With evaluation of equation (2), the RK4 solution function of charging process obtained;

\[
v_{i+1} = v_i + \left( \frac{k_1 + 2k_2 + 2k_3 + k_4}{6} \right)
\]

\[
k_1 = h R C \left( v_0 - v_i \right)
\]

\[
k_2 = h R C \left( v_0 - \left( v_i + \frac{k_1}{2} \right) \right)
\]

\[
k_3 = h R C \left( v_0 - \left( v_i + \frac{k_2}{2} \right) \right)
\]

\[
k_4 = h R C \left( v_0 - \left( v_i + \frac{k_3}{2} \right) \right)
\]

(7)

with \( h = \frac{b-a}{N} \) called step size (\( N \) is a positive integer). Thus, from equation (5) the discharging process have RK4 solution function show in (8).
\[ v_{i+1} = v_i + \left( \frac{k_1+2k_2+2k_3+k_4}{6} \right) \]

\[ k_1 = h \left( \frac{v_i}{RC} \right) \]

\[ k_2 = h \left( \frac{v_i + k_1}{2} \right) \]

\[ k_3 = h \left( \frac{v_i + k_1}{2} \right) \]

\[ k_4 = h \left( \frac{v_i + k_1}{2} \right) \]

\[ v_{i+1} \] used to find the value of voltage \( v \) increased. The process will be iterated for \( N - 1 \) times. From equation (7) and (8) we set \( h = 0.1 \), \( R = 1 \text{k} \Omega \), \( C = 1 \text{ mF} \) and \( v_0 = 3.3 \text{ volt} \). Last, we will obtain the approximation value for the solution of RC Circuit system.

After calculating the numerical simulation, the solution will be plotted using Matplotlib library for Python software. Then, we can investigate the graphic form of charging and discharging process of RC Circuit. From the algorithm obtain graphics as Figure 3.

Figure 3 shows the plot of capacitor voltage when the RC Circuit charging and discharging. On Figure 3 (a) shows the voltage \( v \) across the capacitor voltage (initially not have a charge) will rise exponentially. Thus, Figure 3 (b) show initially capacitor fully charged, then the capacitor discharge through the resistor and the capacitor voltage will fall exponentially with time. The rate of increasing and decreasing of the voltage with time will be dependent upon the product of capacitance and resistance called time constant. Figure 3 shows the best agreement between theoretical solution (3) and (6) with the numerical solution (7) and (8).

4. Hardware Design of RC Circuit

In this section will describe the hardware design of RC Circuit shown in Figure 4. The basic RC Circuit hardware design in this research consist of basic RC Circuit, ADC, and Raspberry Pi model type B+. When the switch turns on (charging process), the charge will flow into the resistor then fill the capacitor.
And when switch turn off (discharging process), the charge on the capacitor will decrease. Both of the processes will obtain the voltages data. To read the real-time of voltage data, Raspberry Pi need ADC (Analog to Digital Conversion) using IC MCP3008. The voltage data will be processed on Raspberry Pi using Python software. Then, the algorithm will show the result as real-time plotting interface.

![RC Circuit Scheme using Fritzing](image)

Figure 4. RC Circuit Scheme using Fritzing.

5. Experimental Result
From Figure 5 shown the hardware realization of the RC Circuit system based Raspberry Pi. This hardware realization consists by basic RC Circuit, ADC using IC-MCP3008, Raspberry Pi model type B+, 7-inch mini LCD (for display real-time plotting graphic of charging and discharging RC Circuit) and mini keyboard (for control). In this research, we have set a fully integrated Raspberry Pi based system for measuring capacitance with data visualization and processing.

![Realization of RC Circuit](image)

(a)

![System Design](image)

(b)

Figure 5. Realization of RC Circuit (a) RC Circuit and Raspberry Pi System, (b) System Design.

We obtain the experimental observation of charging and discharging RC Circuit system (the RC component configuration same as the simulation) shown in Figure 6. As compared to Figure 3 and
Figure 6 shows the best agreement between theoretical solution, numerical simulation and the realization circuit is confirmed.

![RC Circuit Interface](image)

**Figure 6.** Real time RC Circuit Graphic Result (a) Charging, (b) Discharging.

6. Conclusions

In this research, we have studied the RC circuit system. This research shows that the RK4 method successfully can solve RC system, and showing the best agreement if compared with the theoretical solution. Using a Raspberry Pi, we have verified experimentally, with an excellent quantitative agreement, the mathematical model and the numerical simulation that describes the charging or discharging of the capacitor. Raspberry Pi allows us to build a real-time data acquisition and can be used for data visualization and processing. All system can be integrated become mini experiment kit of RC Circuit. Finally, we trust that Raspberry Pi platform is an excellent hardware for low-cost open-source laboratory instrumentation of physics education and another field.

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