Capacitance Regression Modelling Analysis on Latex from Selected Rubber Tree Clones

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Abstract. This paper investigates the capacitance regression modelling performance of latex for various rubber tree clones, namely clone 2002, 2008, 2014 and 3001. Conventionally, the rubber tree clones identification are based on observation towards tree features such as shape of leaf, trunk, branching habit and pattern of seeds texture. The former method requires expert persons and very time-consuming. Currently, there is no sensing device based on electrical properties that can be employed to measure different clones from latex samples. Hence, with a hypothesis that the dielectric constant of each clone varies, this paper discusses the development of a capacitance sensor via Capacitance Comparison Bridge (known as capacitance sensor) to measure an output voltage of different latex samples. The proposed sensor is initially tested with 30ml of latex sample prior to gradually addition of dilution water. The output voltage and capacitance obtained from the test are recorded and analyzed using Simple Linear Regression (SLR) model. This work outcome infers that latex clone of 2002 has produced the highest and reliable linear regression line with determination coefficient of 91.24%. In addition, the study also found that the capacitive elements in latex samples deteriorate if it is diluted with higher volume of water.

1. Introduction

Latex is a cytoplasm that has suspension rubber and non-rubber aqueous serum. The basic components of freshly tapped natural rubber latex are 50-80% water, 15-45% rubber hydrocarbon and approximately 2-4% non-rubber constituents. This composition of latex are influenced by weather, soil condition, clone, tapping system, season and so on [1]. The natural latex is obtained from major rubber trees, known as Hevea Brasiliensis, which grown in ASEAN region namely Malaysia, Indonesia, Thailand, Vietnam and also Cambodia [2].

In the past, the Rubber Research Institute of Malaysia (RRIM) focused on planting rubber with improved latex yield. With the new demand in rubber wood, RRIM initiates breeding activities that emphasize a selection of quick growing clones with a good latex yield as well as timber production.

The selection of these new latex-timber clones (LTC) are based on the important genotypes of the rubber tree such as latex yield, resistance to wind damage, resistance to diseases, girth increment during tapping, respond to wounding, resistance to dryness and so on [3].

Accurate identification of rubber clones is crucial since each clone has different interests in rubber industry. Currently, the rubber clones type can only be discriminated by expert persons as they observe tree features such as shape of leaf, trunk, branching habit and pattern of seeds texture. This
approach is time consuming [4]. Therefore, in order to overcome this constraint, a series of agronomic research on rubber clone identification methods have been proposed.

Dry rubber content (DRC) is one of the possible latex’s features that can be further investigated for clone classification. Various methods that have been reported in literatures for the determination of DRC are Metrolac, Spot, Viscosity, Latex film dialysis, Titration, Microwave attenuation, Low resolution pulsed NMR technique, Spin eco-technique and etc. [5].

Another possible method to determine the DRC of latex is by measuring the capacitance of the latex [6]. This method infers a hypothesis that DRC and dielectric constant of the latex have a linear correlation, and hence, the capacitance of the latex also will vary accordingly. Other investigations that based on their dielectric properties are on the quality of an apple, watermelon, honeydew melons and also a ripeness of banana [7-11].

This paper discusses the initial development of designing a complete sensor for clone detection. It focuses on constructing a capacitance sensor via Capacitance Comparison Bridge (known as capacitance sensor) to measure an output voltage of different latex samples representing selected clones. The capacitance regression modelling on latex is then statistically analyzed with respect to the selected clones.

2. Methodology

The main part of this paper is the development of the capacitance sensor using the Capacitance Comparison Bridge. The workflow of this paper is illustrated in Figure 1.

![Figure 1. Flowchart for capacitance regression modelling analysis](image-url)
2.1 Circuit development and testing

2.1.1 Circuit development

The AC bridge circuit is used to measure the capacitance value of the different latex samples based on the output voltage. Figure 2 shows the Capacitance Comparison bridge circuit [12].

![Capacitance Comparison Bridge Circuit](image)

**Figure 2.** Capacitance Comparison Bridge Circuit

Theoretically, the equation for Capacitance Comparison Bridge can be derived as follows:

\[ Z_1 = R_1 \]  
\[ Z_2 = R_2 \]  
\[ Z_3 = R_3 - jXC_3 \]  
\[ Z_x = R_x - jXC_x \]

During balance condition, there is no output voltage produced, resulting in equation (5).

\[ Z_1Z_x = Z_2Z_3 \]  

By substituting equation (1), (2), (3), and (4) into equation (5), equation (6) is produced.

\[ R_1(R_x - jXC_x) = R_2(R_3 - jXC_3) \]  
\[ R_1R_x - jR_1XC_x = R_2R_3 - jR_2XC_3 \]

Equation (6) is separated into two parts which are real and imaginary part, indicated by equation (7) and (8) respectively.

\[ R_x = \left( \frac{R_2}{R_1} \right) \cdot R_3 \]  
\[ C_x = \left( \frac{R_2}{R_1} \right) \cdot C_3 \]
From the derivation, the prototype circuit is constructed as depicted in Figure 3.

![Figure 3. Prototype of Capacitance Comparison Bridge circuit](image)

2.1.2 Sensor development

Capacitor is an electrical component which consist of two conducting plate of metal separated by the distance or gap called dielectric. The value of the capacitance depends on the area of the plate, the distance between two plates and also the relative permittivity of the dielectric material. Their relationship is explained by equation (9).

\[
C = \varepsilon \frac{A}{D}
\]

Where

- \(C\) = capacitor in farad
- \(A\) = area of the plate
- \(D\) = distance between two plates
- \(\varepsilon\) = relative permittivity of the dielectric material between the plates

Figure 4 depicted a capacitance sensor designed by using the copper plate with the same size, length of 3cm and width of 3.3cm. The distance between two plates is fixed to 0.7cm throughout the experiment.

![Figure 4. Capacitance plate design](image)
The sensor development begins with selecting the value of capacitor, $C_3$, and resistors $R_1$, $R_2$, $R_3$ and $R_x$ that satisfy equation (7) and (8). These resistors are selected based on the resistance in the latex, ranging from 50Ω to 100Ω. However, from the testing conducted, 500Ω resistor gives the best variation of the output voltage. Meanwhile, a 10pF capacitor is selected as the value of $C_3$ due to the more reliable output voltage produced compared to other capacitor's value.

2.2 Data collection

Four rubber tree clones of 2002, 2008, 2014 and 3001 are used in this work. The samples of these clones are obtained from the Rubber Research Institute of Malaysia (RRIM) located at Permatang Station, Kota Tinggi, Johor, Malaysia. All the latex sample has been added with preservative recommended by the Rubber Research Institute of Malaysia (RRIM), Kota Tinggi, Johor and each clone have two samples of latex.

The frequency, distance of capacitance plate and volume of latex are fixed at 100Hz, 0.7cm and 30ml respectively. The frequency is set to 100Hz based on previous research work. The work suggested that 100Hz frequency produces the best effect of capacitance value on the dry rubber content (DRC) [6].

Initially, the capacitance plate sensor is tested in the distilled water to obtain its initial value. Then, the sensor is used to measure both the output voltage and capacitance of 30ml latex sample. The measurements obtained via LCR meter are recorded. This process is repeated for every 10ml of diluted water added to the latex sample until the mixture reaches 60ml. The mixture of latex and diluted water is stirred prior to the measurement for more accurate results. The experiment set-up for data collection is illustrated in Figure 5.

![Figure 5. Data collection process using bridge circuit](image)

2.3 Data analysis

Analyzing data collected for four different rubber tree clones are through observing the effect of diluted water on the capacitance of the latex. The collected data is interpreted into a line graph to obtain the voltage and capacitance relationship. Equations (10)-(11) are used to compute the linear regression equation and the coefficient of correlation, $R$. This parameter explains the linear relationship between voltage and capacitance. Linear relationship between this two independent variable is considered strong if the value of being greater than 0.8. Whilst, if $R$ less than 0.5, it can be described as a weak linear relationship. The perfect correlation is equal to 1 where all the data lies exactly on a straight line.
\[ y = a + bx \]  
\[ R = \frac{n \Sigma xy - \Sigma x \Sigma y}{(n \Sigma x^2 - \Sigma x^2)^{1/2} \cdot (n \Sigma y^2 - \Sigma y^2)^{1/2}} \]

Where,
\[ a = \text{The intercept point of the regression line and the y-axis.} \]
\[ b = \text{The slope of the regression line.} \]
\[ x, y = \text{Independent variable.} \]
\[ n = \text{Number of samples.} \]

3. **Result and Discussion**

The voltage and capacitance of four different clones, namely 2002, 2008, 2014 and 3001 are analyzed and discussed in this section.

### 3.1 Clone 2002

Table 1 shows the voltage and capacitance relationship when latex sample of clone 2002 was diluted with different volumes of water.

**Table 1.** Voltage and capacitance of 2002 clone in different water content.

| Latex (ml) | Water (ml) | Voltage (V) | Capacitance (µF) |
|------------|------------|-------------|------------------|
| 30         | 0          | 0.931       | 16.776           |
| 30         | 0          | 0.935       | 18.221           |
| 30         | 10         | 0.926       | 14.796           |
| 30         | 10         | 0.926       | 13.733           |
| 30         | 20         | 0.919       | 11.526           |
| 30         | 20         | 0.919       | 11.402           |
| 30         | 30         | 0.911       | 9.885            |
| 30         | 30         | 0.910       | 9.675            |

While Figure 6 shows the regression between the capacitance and the output voltage for the respective clone 2002. The value of the correlation coefficient, \( R \) is equal to 0.9552 which indicates strong positive correlation between the voltage and the capacitance values.
Measurements for latex sample of clone 2008 when diluted with different volumes of water are described in Table 2.

Table 2. Voltage and capacitance of 2008 clone in different water content.

| Latex (ml) | Water (ml) | Voltage (V) | Capacitance (µF) |
|------------|------------|-------------|------------------|
| 30         | 0          | 0.925       | 16.865           |
| 30         | 0          | 0.935       | 18.195           |
| 30         | 10         | 0.920       | 13.890           |
| 30         | 10         | 0.925       | 15.300           |
| 30         | 20         | 0.916       | 12.546           |
| 30         | 20         | 0.920       | 13.413           |
| 30         | 30         | 0.909       | 6.517            |
| 30         | 30         | 0.913       | 11.753           |

Hence, Figure 7 shows the regression between the capacitance and output voltage for clone 2008. From the graph plotted, value of the correlation coefficient, \( R \) is 0.8023. It represents a moderate positive correlation between the voltage and capacitance values.
3.3 Clone 2014

Table 3 shows the voltage and capacitance variation when latex sample of clone 2014 was diluted with different volume of water.

Table 3. Voltage and capacitance of 2014 clone in different water content.

| Latex (ml) | Water (ml) | Voltage (V) | Capacitance (µF) |
|------------|------------|-------------|------------------|
| 30         | 0          | 0.938       | 19.254           |
| 30         | 0          | 0.932       | 12.302           |
| 30         | 10         | 0.927       | 15.854           |
| 30         | 10         | 0.918       | 9.973            |
| 30         | 20         | 0.920       | 13.257           |
| 30         | 20         | 0.910       | 7.948            |
| 30         | 30         | 0.910       | 9.673            |
| 30         | 30         | 0.901       | 7.133            |

From the graph in Figure 8, the value of $R$ obtained is 0.8385. This infers that the capacitance and voltage of clone 2014 has moderate positive correlation.

Figure 8. Regression between capacitance and voltage for 2014 clone.

3.3 Clone 3001

Table 4 depicted the voltage and capacitance variation when latex sample of clone 3001 was diluted with different volumes of water.

Table 4. Voltage and capacitance of 3001 clone in different water content.

| Latex (ml) | Water (ml) | Voltage (V) | Capacitance (µF) |
|------------|------------|-------------|------------------|
| 30         | 0          | 0.927       | 14.869           |
| 30         | 0          | 0.928       | 16.627           |
| 30         | 10         | 0.923       | 12.585           |
| 30         | 10         | 0.920       | 13.959           |
| 30         | 20         | 0.915       | 9.770            |
| 30         | 20         | 0.918       | 13.557           |
| 30         | 30         | 0.911       | 9.219            |
| 30         | 30         | 0.913       | 11.246           |
Figure 9 shows that clone 3001 has weak correlation between its voltage and capacitance value with $R$ equal to 0.7301. When comparing with other clones, the variation of the output voltage of clone 3001 can be claimed as less dependent on the value of capacitance.

Hence, the general model of capacitance value of each clone (in microfarad) can be determined by rewriting equation (11) to the linear regression equation as shown in equation (12).

$$\text{Capacitance} = b \cdot \text{Voltage} + a$$

Table 5 shows the summarization of regression modelling with respect to the clone types. It can be observed clone 2002 produces the highest coefficient of determination, $R^2$ values compared to the clone 2008, 2014 and 3001. This implies that with every change in 1 volt, leads to an increment in capacitance value a factor of 1.2354. This work also proved that the output voltage of each clone on its latex can be directly proportional to its capacitance values.

| Clone | Simple Linear Regression Model (SLM) | Coefficient of determination ($R^2$) |
|-------|-------------------------------------|-------------------------------------|
| 2002  | Capacitance = 1.2354 · Voltage + 7.692 | 0.9124 |
| 2008  | Capacitance = 1.1709 · Voltage + 8.2906 | 0.6437 |
| 2014  | Capacitance = 1.4098 · Voltage + 5.5800 | 0.7031 |
| 3001  | Capacitance = 0.7581 · Voltage + 9.3177 | 0.5331 |

4. Conclusion

The motives of this work is to formulate a regression model that can provide capacitance values in terms of micro farad by measuring voltage of latex using Capacitance Comparison bridge circuit. Samples of latex from four selected clones (2002, 2008, 2014 and 3001) commonly used in the rubber industry, were measured using the designed and developed circuit system. These samples were diluted with different volumes of water in order to get variations in the voltage measurement since latex naturally contains water in its composition. Thus, its dielectric would change if water is being added to it. The outcome of the experiment has produced capacitance regression modelling for each of the clone with their respective coefficients of determination. It can be concluded that the capacitance of latex from clone 2002 is strongly correlated with voltage measured from the Capacitance Comparison bridge circuit. This work also proved that by using this capacitance sensor circuit, the output voltage of the latex from these selected clones can be directly proportional to its capacitance values.
Therefore, a lookup table given in Table 5 can be used as a reference for any further investigation work using designed and developed capacitance sensor.

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