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Implementing a dual-touch 4-wire analog resistive touchscreen via regression analysis

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Abstract

As touch mania sweeps across many applications, a large number of venders seek to upgrade to dual-touch if not to multi-touch features, but cannot justify the price of capacitive touchscreens. To get around this, other methods - both legacy and cutting edge – are available. The idea is to create inexpensive alternatives to capacitive touchscreens or retrofit dual-touch/multi-touch gestures to existing resistive-touchscreen designs, for example.

This paper introduces a new scheme to detect any dual-touch on an analog resistive touchscreen. A 4-wire version was chosen due to the simplicity of its structure. Both linear and polynomial regression, was used to support the ability of detecting any position. Four screen sizes, 4.3-inch, 5.7-inch, 7-inch, and 10.2-inch, were explored. The findings revealed that resistance changes during touch can be utilized for detecting the coordinates of finger(s), for a single-touch and any dual-touch. The maximum error across all screen sizes, evaluated by RMSE, is under 3mm from the exact position on both the X and Y-axes.

Keywords: Dual-touch, 4-Wire resistive touchscreen, Analog resistive touchscreen, Regression analysis

1. Introduction

Touchscreens have becoming increasingly popular. They are popping up everywhere and are gradually taking over our lives. They are not limited to smartphones and tablets, but they are literally everywhere, from ATMs, kiosks, navigation systems, automobiles, appliances, medical devices, to game consoles and even touchpads on laptops or PCs. There are two common types of touchscreens. The earlier type is called a capacitive touchscreen. These are normally found on upscale devices, which respond to the slightest touch, allow multi-touch and are generally highly sensitive (to bare fingers). Some have slightly longer response times, that require some pressure or a stylus, that do not natively support multi-touch abilities, but work no matter what is used to touch with. The latter type is called a resistive touchscreen. Due to its advantage of low production costs, the aim of this work is to enhance resistive technology. This paper presents a method for detecting independent dual-touch positions on a 4-wire analog resistive touchscreen using polynomial regression.

2. Literature review

This section starts with some brief information on the categories of touch inputs. Then, the two common types of touchscreens are reviewed in depth, including a brief discussion of various attempts to implement dual-touch and multi-touch features on resistive touchscreens. Next, details of the 4-wire analog resistive touchscreen are presented. Finally, the concept of polynomial regression and performance evaluation are briefly covered.

2.1 Categories of touch input

Touch inputs (Figure 1) can be categorized as 1-finger (so called a single touch or with stylus), 2-finger (often called dual-touch), 3-finger and 4-finger. Multi-touch technology supports the use of two or more concurrent touch-based commands, hence dual-touch can be considered as multi-touch in many cases.

The basic gestures for single-touch and dual-touch are given in Figures 2 and 3, respectively.

2.2 Types of touchscreen

Two common types of touchscreen are capacitive and resistive touchscreens.

2.2.1 Capacitive touchscreen

The capacitive touchscreen was developed first. Utilizing the electrical properties of the human body, a capacitive touchscreen [1-2] consists of two separate layers of glass, coated with conductor. As human body is an electrical charge conductor. A finger touch on the glass of a capacitive surface changes the local electrostatic field.

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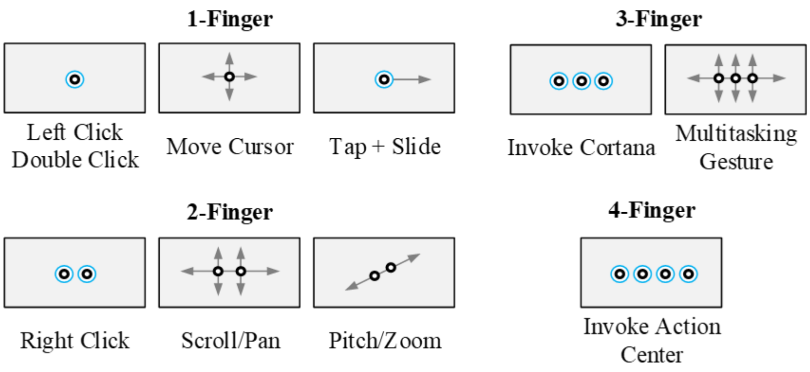


Figure 1 Categories of Touch Inputs [3]

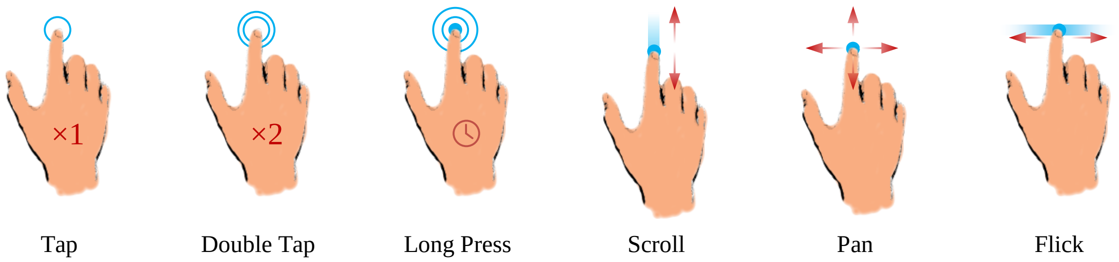


Figure 2 Basic Single-touch Gestures [4]

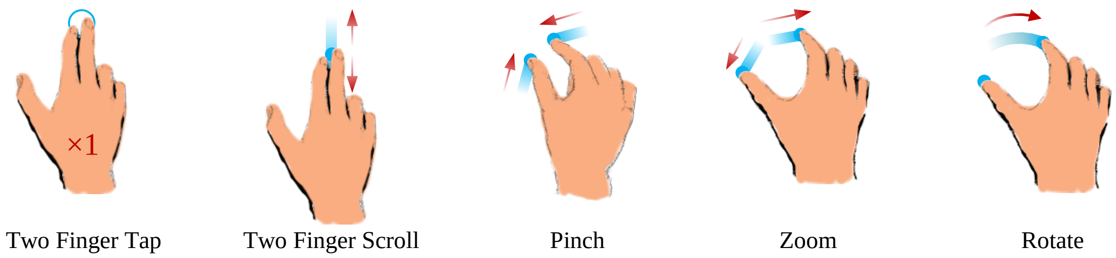


Figure 3 Basic Dual-touch Gestures [4]

The system constantly monitors the movement of each tiny capacitor to find the exact screen area that has been touched by a finger. Since this touchscreen type consists of a single main layer, it continually became finer as technology progressed. This screen is not only more impressionable and accurate, the display itself can be much sharper, as seen on smartphones. Of course, capacitive touchscreens can also make use of multi-touch gestures, but only by using several fingers simultaneously. If one finger is touching one part of the screen, the screen will not be able to precisely sense another touch. Furthermore, since this technology relies on the conductive nature of the human body, wearing gloves or having wet fingers renders it ineffective. Also, the complex structure of these screens leads to high production costs. Lastly, glass surfaces are prone to breaking.

2.2.2 Resistive touchscreen

A resistive touchscreen [1, 5] consists of several layers, of which flexible plastic and glass are two significant electrically resistive layers. The front surface of a resistive touchscreen panel is a scratch-resistant plastic coated with a conductive substance. The second layer is either made of glass or hard plastic and is also coated with conductive substance. These layers face each other and are divided by a tiny gap. An electrical resistance is formed between the layers in such a way that charges run from side-to-side on one layer and top-to-bottom on the other.

When a tip of a finger or stylus presses down on the outer surface, the conductive films meet. Measurement of the resistance of both the layers at the contact point makes a correct measurement of the touch position possible. Preciseness also depends on the evenness of the coating of conductive layers on both surfaces.

There are some disadvantages including lack of sensitivity requiring more force when pressing the screen, poor contrast due to increased reflectivity from an extra layer of material in the screen and these screens lack full multi-touch functionality. Still, the resistive touchscreen is the most common type. Except for modern smartphones and tablets, most touchscreens are actually resistive touchscreens, accounting for over 75% of the market [6-7]. This is because of its low production costs, high resistance to dust and water, the ability to be actuated with a finger, gloved hand or stylus. It is thus suited for handwriting recognition [8].

There are two categories of resistive touchscreen technologies, digital and analog [5]. The following sections provide a detailed explanation of both categories.

- *Digital Resistive Touchscreens*, sometimes referred to as a matrix touchscreen. The conductive coating is etched (or selectively applied) to form rows on one layer and columns on an opposing layer. When assembled, the rows and columns form a matrix of switches. Each switch has a permanent discrete location and the size cannot change. The resolution is dependent on the number of rows and columns.

- *Analog Resistive Touchscreen* is a construction used on pen recognition type computers or when a much higher resolution of switches is required than is possible with the digital design. Resolution of the analog touchscreen is limited only by the lighted panel behind the touchscreen.

2.3 A Chosen 4-wire analog resistive touchscreen.

A 4- wire analog touchscreen, Figure 4, is a two-dimensional sensing device that is constructed from two sheets of material separated by a very small gap. The conventional construction is a sheet of glass accommodated on a stable bottom layer and a sheet of polyethylene (PET) as a flexible top layer. These sheets are coated with a resistive substance, usually a metal compound called indium tin oxide (ITO). ITO is thinly and uniformly sputtered onto both the glass and the PET layer. When the PET film is pressed down, the two resistive surfaces meet. The position of this meeting (a touch) can be read by a touchscreen controller circuit. Two electrodes on each layer, left (X+) and right (X-) on the ITO (top) layer and top (Y-) and bottom (Y+) on the PET (bottom) layer, as in Figure 4, are necessary for touch position capturing.

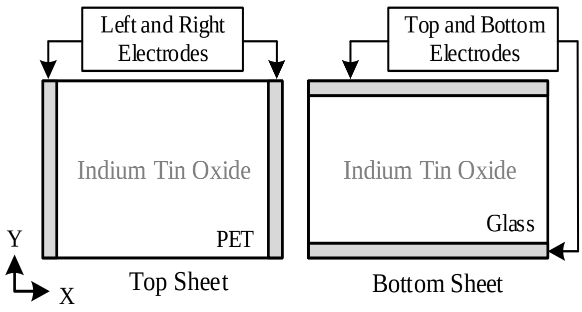


Figure 4 The 4-wire Resistive Touchscreen Structure [9-10]

To know if the coordinate readings are valid, there must be a way to detect whether the screen is being touched. This can be done by applying a positive voltage (Vcc) to Y+ through a pull-up resistor and applying ground to X–. When there is no touch, Y+ is pulled up to the positive voltage. When there is a touch, Y+ is pulled down to ground as shown in Figure 5.

The X and Y coordinates of a touch on a 4-wire touch screen are read in two steps. This measurement scheme is shown in Figure 6.

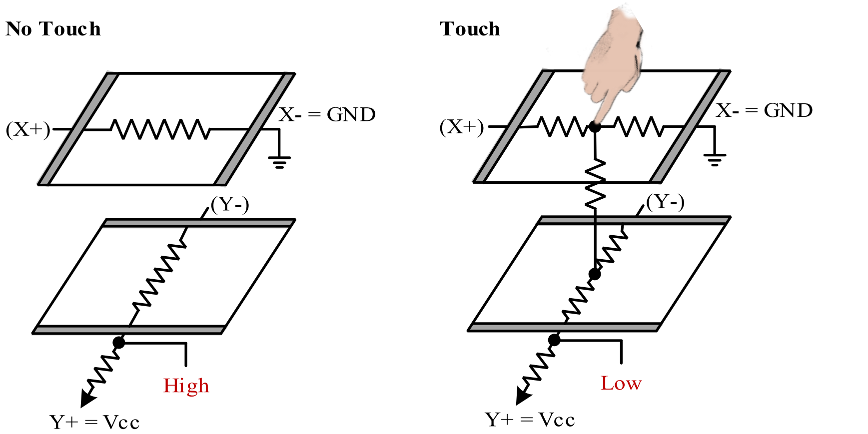


Figure 5 Touch Detection Mode [11]

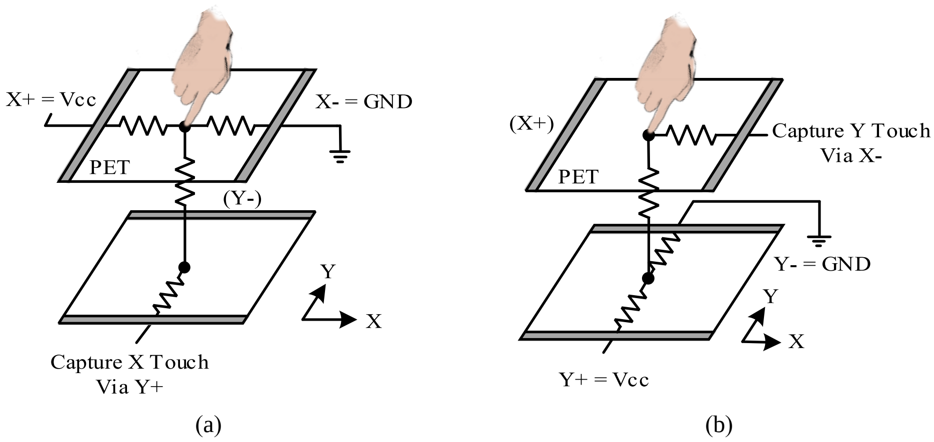


Figure 6 Capturing X Touch (a) and Y Touch (b)

The X touch position can be obtained, as shown in Figure 6a, by driving the X+ to positive voltage (Vcc) and the X- to ground (GND). While Y- is left unconnected, the voltage at Y+ is measured. That is where the top layer meets the bottom layer. The ratio of this measured voltage to the drive voltage applied is equal to the ratio of the x coordinate to the width of the touch screen. For the same ratio, the voltage can also be measured at Y- while leaving Y+ unconnected.

Similarly, The Y touch position can be obtained, as shown in Figure 6b, by driving Y+ to positive voltage (Vcc) and Y- to ground (GND). While X- is left unconnected, the voltage at X+ is measured. Again, that is where the top layer meets the bottom layer. The ratio of this measured voltage to the applied drive voltage is equal to the ratio of the Y coordinate to the height of the touch screen. For the same ratio, the voltage can also be measured at X- while X+ is left unconnected.

The X and Y coordinates can then be calculated via Equations (1) and (2):

$$\mathrm{Y} = \frac{\mathrm{V_{X+}}}{\mathrm{V_{Drive}}} \times \mathrm{height_{screen}} \tag{1}$$

$$\mathrm{X} = \frac{\mathrm{V_{Y+}}}{\mathrm{V_{Drive}}} \times \mathrm{width_{screen}} \tag{2}$$

2.4 Related works

Previous research has attempted to enable resistive touchscreen technology to support dual-touch if not multi-touch gestures. For instance, Chang and Lin [12] divided a resistive touchscreen in a 2x2 mm matrix. Using a voltage divider circuit, multi-touch could be detected. However, the position resolution depended on granularity of the matrix. Next, Calpe et al. [13] developed a new method to capture a touch transition (i.e., pitch in/out or rotation) by detecting changing voltages in a different periods of time. However, their work could not detect independent multiple touches.

2.5 Data regression

2.5.1 Linear regression

Linear regression is the most basic type of regression and commonly used predictive analysis. The simplest equation for linear regression is given by Equation (3).

$$\mathbf{a} = \mathbf{bz} + \mathbf{c} \tag{3}$$

where z is the independent variable and a is the dependent variable. The slope of the line is b, and c is the y-intercept (the value of a when z = 0).

2.5.2 Polynomial regression

Polynomial regression [14] is a type of linear regression to fit nonlinear data into a least squares Linear Regression model, allowing a single $\boldsymbol{A}$ variable to be forecasted using a $\boldsymbol{B}$ variable in various orders in a polynomial function. The pattern of the function is shown in Equation (4).

$$\mathbf{A_n} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1}\mathbf{B_1} + \boldsymbol{\beta_2}\mathbf{B_2}^{\mathbf{2}} + \boldsymbol{\beta_3}\mathbf{B} + .. + \boldsymbol{\beta_n}\mathbf{B_n}^{\mathbf{z}} \tag{4}$$

where:

A_n is the independent variable

B_1, B_2,... B_n are the predictor variables

β_0 is a constant;

β_1, β_2 ,... β_n are the coefficients that are multiplied by the predictor variables

In polynomial regression, different of orders of $\boldsymbol{z}$ are sequentially included in function resulting in a best fit.

2.6 Performance Evaluation

The method of finding errors in this research was based on the root mean square error (RMSE). It was been chosen to evaluate this work. Equation (5) presents the calculation for RMSE [15]:

$$\boldsymbol{RMSE} = \sqrt{\frac{\mathbf{1}}{\boldsymbol{n}}\sum_{\boldsymbol{i=1}}^{\boldsymbol{n}}(\boldsymbol{z_m} - \boldsymbol{z_c})^{\mathbf{2}}} \tag{5}$$

where $\boldsymbol{z_m}$ is the measured value, $\boldsymbol{z_c}$ is the calculated value and n is the number of data points.

3. Research methodology

Preliminary work was done to find if the ratio of the measured voltages at X+ and X- had the same value for only a single-touch. In the same way that the ratio of the measured voltages at Y+ and Y- were determined for a single-touch. For dual-touch (and also multi-touch) various voltages were obtained according to when they are measured. This finding is the key to enabling dual-touch in analog resistive technology.

Per single-touch, finding the touch coordinates can be accomplished as discussed in Section 2. However, the voltage obtained in this way will not be sufficient to identify all coordinates when touched with multiple fingers. The three following steps can be performed to find any independent coordinates for a dual-touch. The first step is to identify whether it is a single-touch or a dual-touch. The next step is to obtain the distance between positive values, on both the X and Y axes. Then, the exact coordinate for each finger is calculated.

3.1 Determination of a single- or dual-touch

The experiment started from marking a 1 cm^2 grid both on X and Y axes on each screen layer, i.e., top and bottom layers, as in Figure 7.

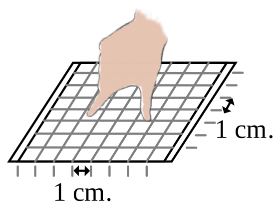


Figure 7 1 cm^2 Grid Screen

In addition to the previously discussed voltage measuring schemes, additional voltages at Xt and Yt must be measured, as shown in Figure 8, This is done first for a single touch at all coordinates on the grid and then for all combinations of 2-coordinate touches on the grid.

After this tedious procedure, the first results are for single-touch gestures. Table 1 shows V_{Xt} and V_{Yt} for single-touch, while Figure 9 presents a comparison of calculated and measured V_{Xavg} and V_{Yavg}.

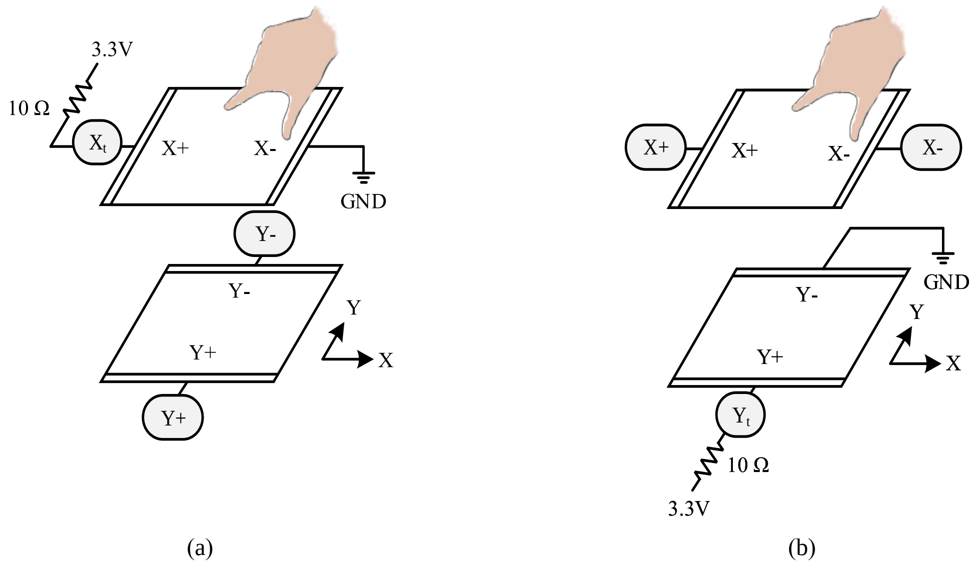
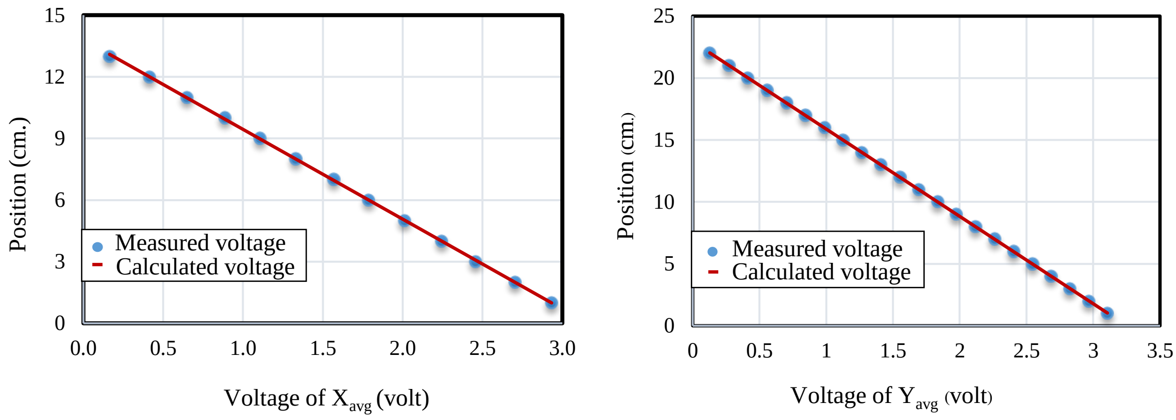


Figure 8 Measurement on an X axis (a) and Y axis (b)



(a) V_{Xavg} (b) V_{Yavg}

Figure 9 Comparison of Calculated Voltage and Measured Voltage

Table 1 Voltage of Xt and Yt with a Single-touch

Touch positions				V_{Xt} (volt)	V_{Yt} (volt)
X1	Y1	X2	Y2		
1	1	1	1	3.2945	3.2642
2	1	2	1	3.2945	3.2642
3	1	3	1	3.2945	3.2642
2	2	2	2	3.2945	3.2642

Then all measured V_{Xt} and V_{Yt} for dual-touch were determined as shown in Figures 10 and 11.

This data can be translated so that any touch with the same distance on X axis, regardless the distance on the Y axis, gives the same voltage at Xt. The same is true for the Y axis. For example, the distance on X axis for (0, 0) to (5, 0), (0, 0) to (5, 7) coordinates are both 5. Similarly, the distance on Y axis for (0, 0) to (0, 3), (0, 0) to (2, 3) are both 3. Furthermore, for all single-touch no matter where on the grid, there is only one corresponding voltage at Xt, V_{Xt_0}, and one at Yt, V_{Yt_0}. That is how a single-touch can be identified among other touches.

As a result, the voltage at Xt and Yt can identify four touch styles as follows:

1. $V_{Xt} = V_{Xt\_0}$ and $V_{Yt} = V_{Yt\_0}$: Single-touch (X, Y).
2. $V_{Xt} \neq V_{Xt\_0}$ and $V_{Yt} = V_{Yt\_0}$: Dual-touch on the same Y axis: (X1, Y) and (X2, Y) as in Figure 12a. Examples of V_{Xt} and V_{Yt} for this case can be seen in Table 2.
3. $V_{Xt} = V_{Xt\_0}$ and $V_{Yt} \neq V_{Yt\_0}$: Dual-touch on the same X axis: (X, Y1) and (X, Y2) as in Figure 12b. Examples of V_{Xt} and V_{Yt} for this case can be seen in Table 3.
4. $V_{Xt} \neq V_{Xt\_0}$ and $V_{Yt} \neq V_{Yt\_0}$: Any other dual touch that does not align either on X or Y axis: (X1, Y1) and (X2, Y2) as in Figure 13.

Table 2 Examples of V_{Xt} and V_{Yt} with dual-touch on the same Y axis (X1=X2)

X and Y Coordinate				V_{Xt} (volt)	V_{Yt} (volt)
X1	**Y1**	**X2**	**Y2**		
2	2	2	3	3.2943	3.2641
2	2	2	4	3.2943	3.2640
2	2	2	5	3.2943	3.2635
2	2	2	6	3.2943	3.2631

Table 3 Examples of V_{Xt} and V_{Yt} with Dual-touch on the same X axis (Y1=Y2)

X and Y Coordinate				V_{Xt} (volt)	V_{Yt} (volt)
X1	**Y1**	**X2**	**Y2**		
1	2	13	2	3.2917	3.2642
1	2	14	2	3.2911	3.2642
1	2	15	2	3.2906	3.2642
1	2	16	2	3.2902	3.2642

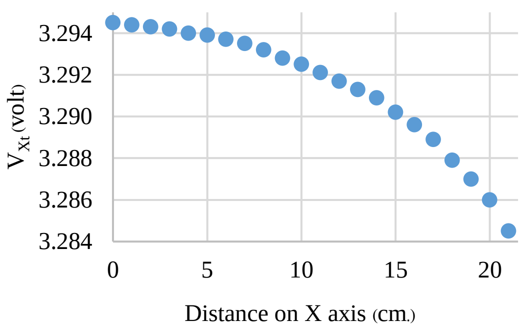


Figure 10 The Relation Between V_{Xt} and Distance on the X-axis.

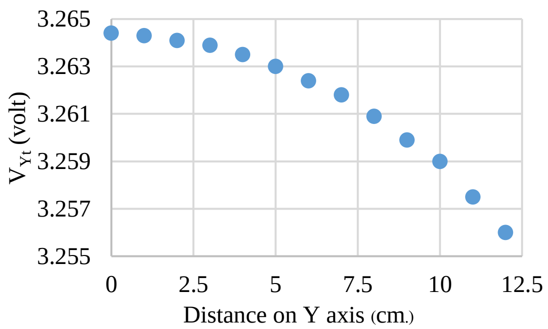


Figure 11 The Relation Between V_{Yt} and Distance on the Y-axis.

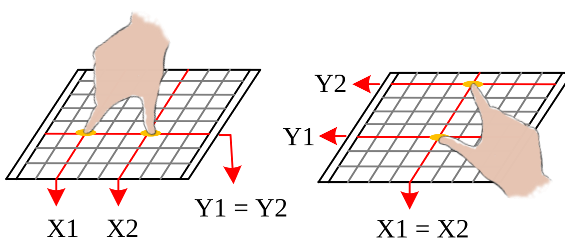


Figure 12 (a) Dual- touch on the Same X-axis, (b) Dual-touch on the Same Y-axis

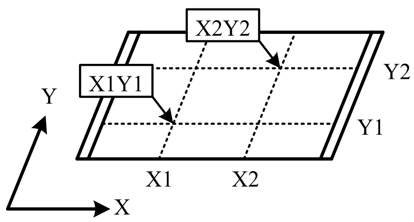


Figure 13 Any Other Dual-touch (X1, Y1) and (X2, Y2)

3.2 Regression to find the distance

Using these processes, all obtained V_{Xt} and V_{Yt} values indicated distances on X and Y-axes, respectively. However, those distances are rather discretely snapped to grids. To obtain coverage for all distances, a data regression was performed. As the data were not quite linear, polynomial regression was chosen for its simplicity. First through third degree polynomial regressions were explored.

The distances of on X and Y-axes can then be derived from Equations (6) and (7) for a first degree polynomial regression. Equations (8) and (9) define a second degree polynomial regression while Equations (10) and (11) define a third degree polynomial regression.

$$D_{X\_1st} = -2{,}076.57Xt + 6{,}845.34 \tag{6}$$

$$D_{Y\_1st} = -1350.4Yt + 4410.6 \tag{7}$$

$$D_{X_{2nd}} = -233{,}369.6\,(Xt)^2 + 1{,}533{,}550.85Xt - 2{,}519{,}350.61 \tag{8}$$

$$D_{Y_{2nd}} = -156{,}067.73\,(Yt)^2 + 1{,}016{,}390.48Yt - 1{,}654{,}798.18 \tag{9}$$

$$D_{X_{3rd}} = -32{,}571{,}048.46\,(Xt)^3 + 321{,}223{,}511.64\,(Xt)^2 - 1{,}055{,}995{,}290.48Xt + 1{,}157{,}166{,}128.74 \tag{10}$$

$$D_{Y_{3rd}} = -30{,}623{,}041.86(Yt)^3 + 299{,}369{,}273.16(Yt)^{\mathbf{2}} - 975{,}540{,}106.73Yt + 1{,}059{,}649{,}042.91 \tag{11}$$

Table 4 RMSE of Dx and Dy

Degree of Polynomial Regression / Screen Size (inches)	RMSE of Dx (cm)			RMSE of Dy (cm)		
	1st	2nd	3rd	1st	2nd	3rd
4.3	0.75	0.36	0.24	0.40	0.18	0.10
5.7	0.58	0.31	0.19	0.57	0.31	0.19
7	1.22	0.53	0.32	0.67	0.30	0.16
10.2	1.76	0.73	0.45	1.09	0.52	0.33

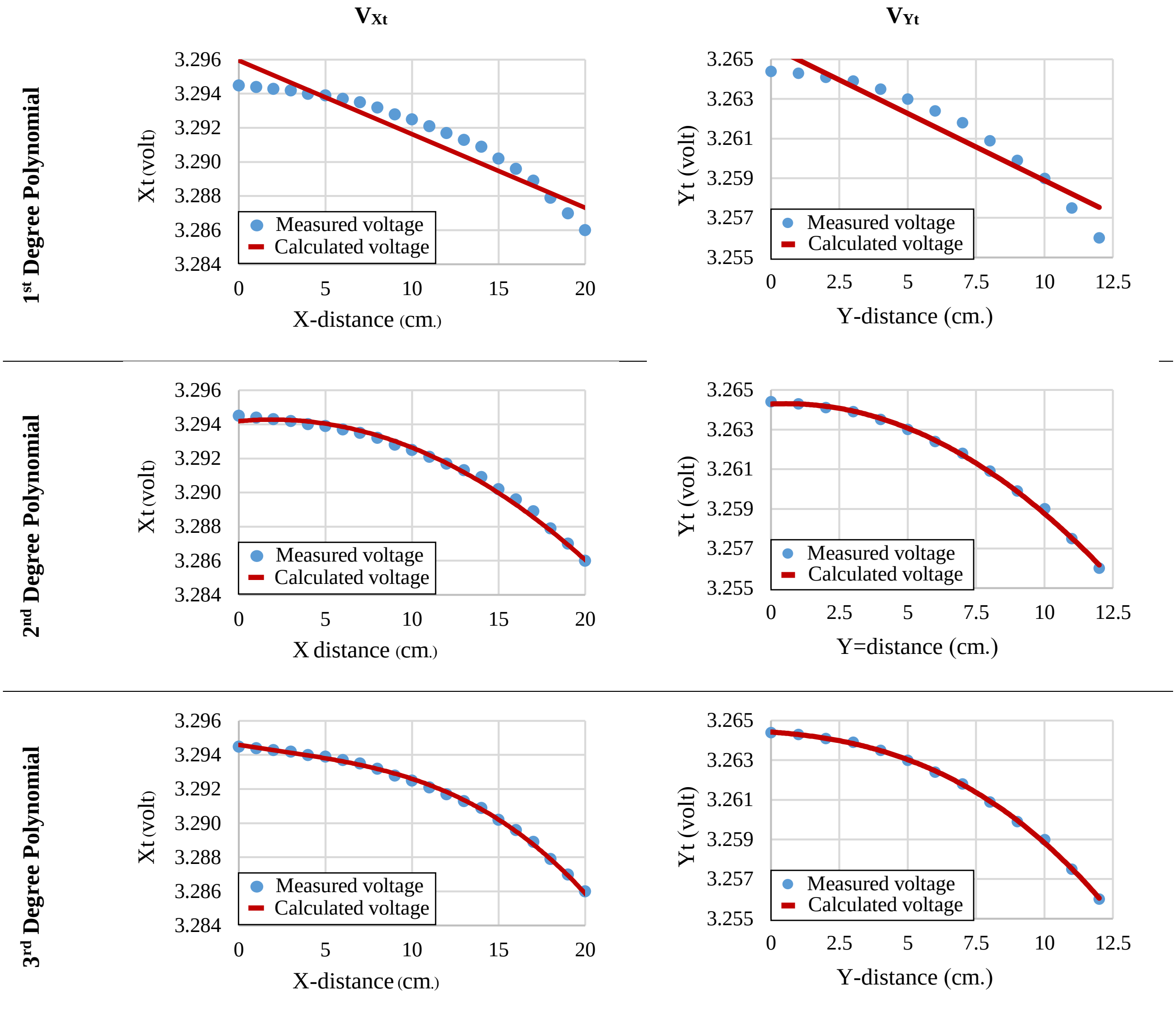


Figure 14 Comparison of Measured and Calculated Voltages

Figure 14 shows the result of the first through third order polynomial regressions for all measured V_{Xt} and V_{Yt} values, while Table 4 lists the RMSEs of Dx and Dy for all the first through third order polynomial regressions, for four screen sizes given in Table 4.

3.3 Calculation for the exact two touched positions

For each single-touch, identified via V_{Xt_0} and V_{Yt_0}, measuring V_X can be equivalently done at Y+ or Y-, a V_Y can be measured using X+ or X-. Hence:

$$V_X = V_{Xavg} = \frac{(V_{X\_Y+})+(V_{X\_Y-})}{2} \tag{12}$$

$$V_Y = V_{Yavg} = \frac{(V_{Y\_X+})+(V_{Y\_X-})}{2} \tag{13}$$

Calculating a dual-touch requires a bit more work. Once the equations for regressing Dx and Dy have been determined, any further touch can easily be identified via the following steps:

For capturing an X touch, after driving X+ to Vcc (3.3V) and X- to GND, Vx is measured both at Y- and Y+, yielding V_{X_Y-} and V_{X_Y+}, respectively. Furthermore V_{Xt} is measured for a calculated Dx. Similarly, a Y touch is captured in the same way and V_{Xt} is measured for a calculated Dy. X1, X2, Y1 and Y2 can be calculating from Equations (14) - (17).

$$X1 = \frac{(V_{X\_Y+})+(V_{X\_Y-})}{2} - \frac{Dx}{2} \tag{14}$$

$$X2 = \frac{(V_{X\_Y+})+(V_{X\_Y-})}{2} + \frac{Dx}{2} \tag{15}$$

$$Y1= \frac{(V_{Y\_X+})+(V_{Y\_X-})}{2} - \frac{Dy}{2} \quad (16)$$

$$Y2= \frac{(V_{Y\_X+})+(V_{Y\_X-})}{2} + \frac{Dy}{2} \quad (17)$$

Four common but different 4-wire analog resistive touchscreen sizes were explored. There were 4.3-inch (5.7cm×10cm), 5.7-inch (9cm×12cm), 7-inch (9.2cm×15.5cm) and 10.2-inch (13.5cm×22.5cm) screens. Finally, the average RMSEs (mm.) for each screen size for all degrees of polynomial regression are reported in Tables 5 and 6.

Table 5 RMSE for X positions

Screen Sizes	Polynomial		
	1st	2nd	3rd
4.3	4.1	2.7	2.3
5.7	4.3	2.6	2.0
7	4.3	2.5	2.1
10.2	4.1	2.6	2.1

Table 6 RMSE for Y positions

Screen Sizes	Polynomial		
	1st	2nd	3rd
4.3	3.0	2.4	2.3
5.7	3.6	2.5	2.2
7	3.0	2.5	2.4
10.2	3.2	3.0	2.7

4. Conclusions

In a world that is increasingly focused on capacitive touch technology, resistive solutions should not be ignored due to its advantages. These include their less expensive screens and their capability of supporting other kinds inputs than bare fingers.

This paper presents a new approach to detect any dual-touch on a 4-wire analog resistive touchscreen. Four screen sizes, 4.3-inch, 5.7-inch, 7-inch, and 10.2-inch, have been tested and both linear and polynomial regressions were applied.

The experimental results showed that detecting the coordinates of finger(s), for both a single-touch and any dual-touch, can be done by determining resistance changes when touched. With a grid size of 1 cm^2, the maximum error across all screen sizes, evaluated by RMSE, was less than 3mm from the actual position on both the X and Y axes. A smaller grid size would yield less error. Furthermore, the proposed method can be exploited using any screen size. Without repeating the process for each screen size, the rule of three can be applied to use the same calculation equation with a bigger or smaller screen size. Using the rule of three scheme, both screen size and grid size must be in the same proportion. Hence, the errors will be larger or smaller error in the same ratio.

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