TN0074
Technical note

Calibration procedure for a resistive touchscreen system based on the STMPE811

Introduction

This document describes the calibration procedures for a resistive touchscreen system based on the STMPE811 8-bit port expander with advanced touchscreen controller. The system consists of a screen to display information to the user, and a touch sensor panel controlled by the STMPE811 to detect and define the location of a touch event. Each component has its own resolution and independent coordinate system.

It may not be possible to use the touch coordinates produced by the touchpanel directly as the screen coordinates. This is because typically there is a mismatch between the two coordinate systems caused by factors such as mechanical placement error, scale difference, or the series resistance of the tracks connecting the touchpanel and its driver IC.

A set of transfer functions must be used to convert the touchpanel coordinates to the screen coordinates. The constants of the functions are defined during the calibration process.

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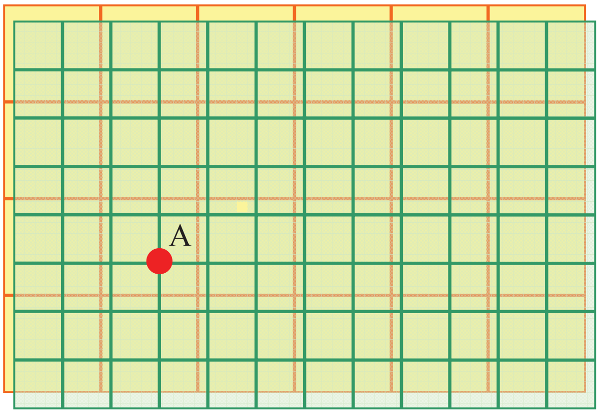
2-constants calibration only corrects misalignment on the X and Y axes, both scaling factor and offset. Angle misalignment is not corrected. This type of calibration is suitable when the angle error is negligible (small screen) and a simple calculation is required. The procedure for 2-constants calibration is quite straightforward.

Figure 1. Mismatch which can be corrected with 2-constants calibration



Point A in *Figure 1* is located at coordinate (3,3) on the touchpanel, but on the screen it is located at coordinate (1.6,1.4). This condition can be corrected using the following transfer function:

Equation 1

$$Y_D = aY + b$$

Equation 2

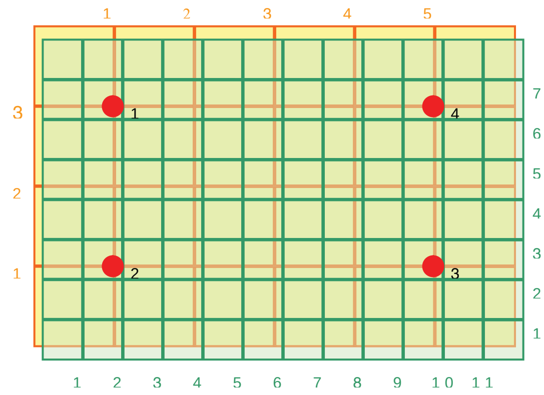
$$X_D = cX + d$$

Where:

- Y_D is the screen's Y value
- X_D is the screen's X value
- Y is the touchpanel's Y value
- X is the touchpanel's X value
- a, b, c, d are the transfer function parameters

The two unknowns in both equations can be resolved by choosing two points and defining them on the screen. For an example, please refer to *Figure 2*.

Figure 2. Example of calibration points



The calibration points are described in *Table 1* below:

Table 1. 2-constants calibration points

Point	X_D	Y_D
1	1	3
2	1	1
3	5	1
4	5	3

After the user touches the points on the touchpanel, the panel coordinates are as shown in *Table 2*, assuming there is some variation in touch locations.

Table 2. Input from touchpanel for defined points

Point	X	Y
1	1.8	6.3
2	1.85	2.3
3	9.75	2.2
4	9.8	6.35

Only two points are required to solve the equations, but it is recommended to perform the equations twice and use an average of the results.

In this illustration, there are two groups of equations to be solved. Group 1 is defined as follows:

Equation 3

$$Y_D = a_1 Y + b_1$$

Equation 4

$$X_D = c_1 X + d_1$$

To solve these equations, points 1 and 3 are used:

- Y axis

Equation 5

$$\begin{pmatrix} Y_{D1} \\ Y_{D3} \end{pmatrix} = \begin{pmatrix} a_1 \\ b_1 \end{pmatrix} \begin{pmatrix} Y_1 & 1 \\ Y_3 & 1 \end{pmatrix}$$

$$\begin{pmatrix} 3 \\ 1 \end{pmatrix} = \begin{pmatrix} a_1 \\ b_1 \end{pmatrix} \begin{pmatrix} 6.3 & 1 \\ 2.2 & 1 \end{pmatrix}$$

Solving the matrix results in a1 = 0.487 and b1 = -0.073

- X axis

Similarly, the results are c1 = 0.503 and d1 = 0.095

Group 2 is defined as follows:

Equation 6

$$Y_D = a_2 Y + b_2$$

Equation 7

$$X_D = c_2 X + d_2$$

Point 2 and 4 are used to solve these equations:

- Y axis

Solving the equation:

Equation 8

a2 = 0.494 and b2 = -0.136

- X axis

Solving the equation:

Equation 9

c2 = 0.497 and d2 = 0.130

At this point, take an average of the results from the two groups of equations, and this is the final result of the calibration.

Table 3. Final calibration result using the average of the two point groups

Parameter	1	2	Average
a	0.487	0.494	0.4905
b	-0.073	-0.136	-0.1045
c	0.503	0.497	0.5
d	0.095	0.130	0.1125

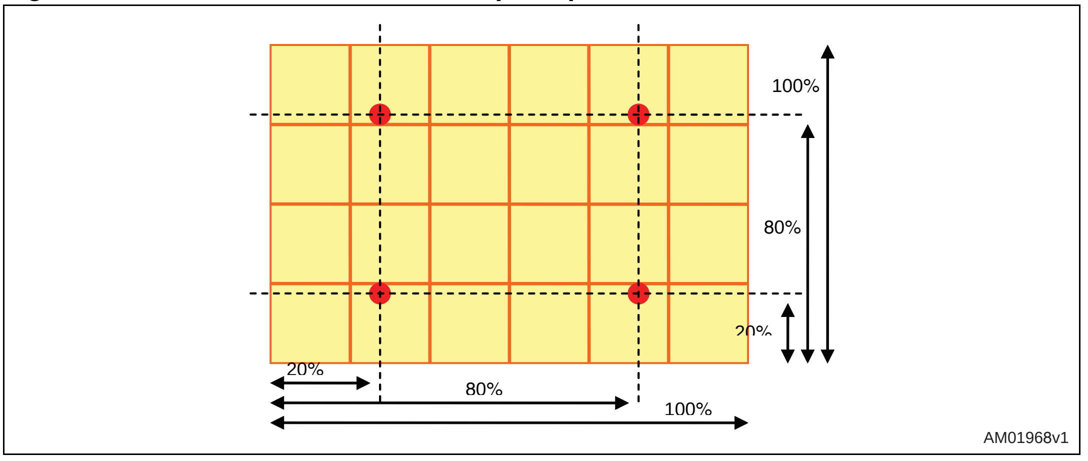
Hence, the transfer functions from the touchpanel coordinates to the display coordinates are:

$$Y_D = 0.4905X - 0.1045$$
$$X_D = 0.5X + 0.1125$$

The points chosen for calibration should be capable of representing the entire screen area. The recommended positions are the corners of the screen, but not too close to the center of the screen or the borders of the touchpanel. Choosing calibration points too close to the center results in poor representation of the areas further away from the center. However, if the points are too near the edges, any mechanical imperfections present in the panel may affect the result of the calibration.

It is recommended to use points located at 20% and 80% of the X and Y axes, as shown in *Figure 3* below.

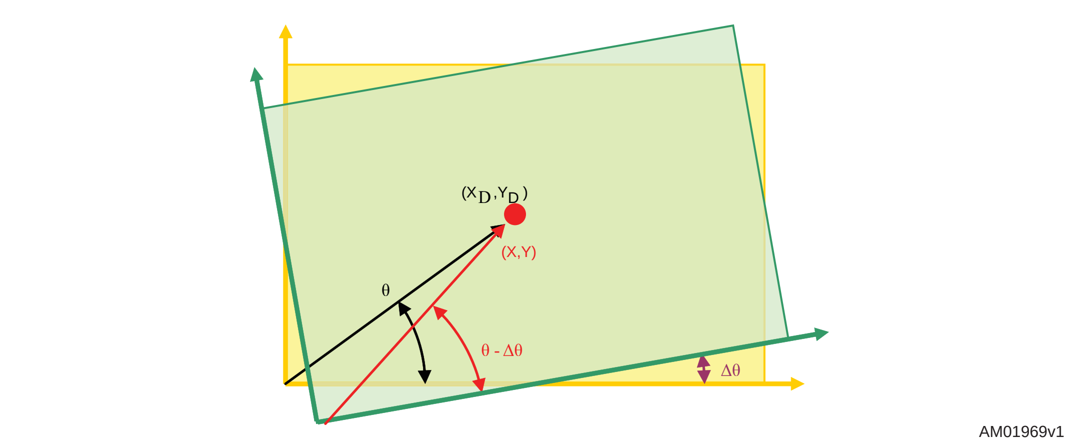
Figure 3. Recommended calibration point positions: 20% and 80% of X and Y axes



2 3-constants calibration

This method of calibration corrects misalignment of the X and Y axes, as well as angle misalignment. *Figure 4* shows an illustration of mechanical misalignment.

Figure 4. Mechanical placement error which includes angle error



Mathematical expressions can be derived from *Figure 4*. They are:

Equation 10

$$(X, Y) = [R\cos\theta, R\sin\theta]$$

Equation 11

$$(X_D, Y_D) = [R_D\cos(\theta - \Delta\theta), R_D\sin(\theta - \Delta\theta)]$$

Introducing a scale difference between the panel and the display, we have:

Equation 12

$$(X_D, Y_D) = [K_X R\cos(\theta - \Delta\theta), K_Y R\sin(\theta - \Delta\theta)]$$

If an error is introduced in the X and Y axis (represented by X_T and Y_T) of *Equation 12*, the resulting equation is:

Equation 13

$$(X_D, Y_D) = [K_X R\cos(\theta - \Delta\theta) + X_T, K_Y R\sin(\theta - \Delta\theta) + Y_T]$$

Using trigonometric identity with the assumption that $\Delta\theta \to 0$, the result is:

Equation 14

$$\cos(\theta - \Delta\theta) = \cos\theta + \Delta\theta\sin\theta$$
$$\sin(\theta - \Delta\theta) = \Delta\theta\cos\theta - \sin\theta$$

and *Equation 13* can be modified to:

Equation 15

$$X_D = K_X R \cos\theta + K_X R \Delta\theta \sin\theta + X_T$$

Equation 16

$$Y_D = K_Y R \Delta\theta \cos\theta - K_Y R \sin\theta + Y_T$$

To simplify the equations, *Equation 15* and *16* can be rewritten as:

Equation 17

$$X_D = AX + BY + C$$

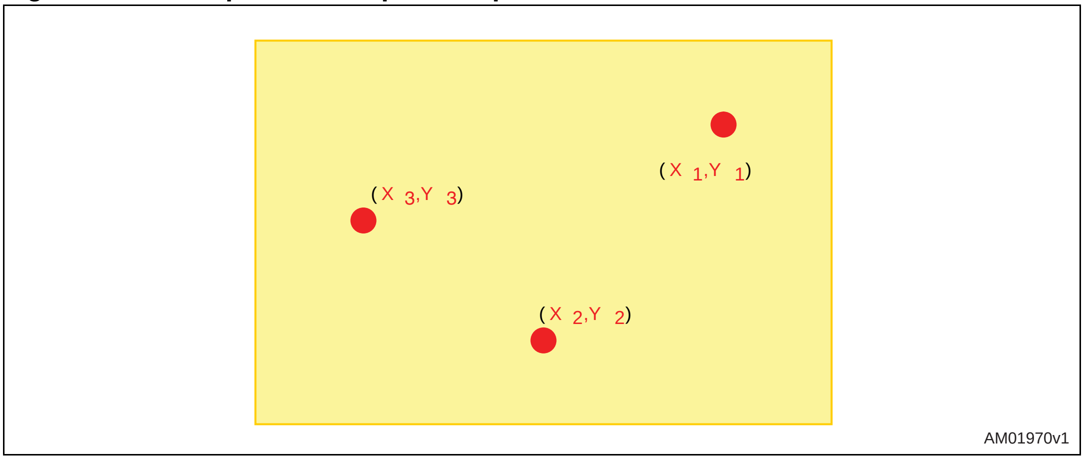
Equation 18

$$Y_D = DX + EY + F$$

It is clear that to solve *Equation 17* and *18*, at least 3 points are required. The points used must be independent of each other (not in a straight line).

The 3 independent points chosen are illustrated in *Figure 5*. The coordinate (XDn,YDn) contain the chosen points of the screen coordinate, while (Xn,Yn) represents the user's input on the touchpanel corresponding to the points displayed on the screen.

Figure 5. Example of 3 independent points



The matrix representation is as follows:

Equation 19

$$\begin{pmatrix} X_{D1} \\ X_{D2} \\ X_{D3} \end{pmatrix} = \begin{pmatrix} X_1 & Y_1 & 1 \\ X_2 & Y_2 & 1 \\ X_3 & Y_3 & 1 \end{pmatrix} \times \begin{pmatrix} A \\ B \\ C \end{pmatrix}$$

Equation 20

$$\begin{pmatrix} Y_{D1} \\ Y_{D2} \\ Y_{D3} \end{pmatrix} = \begin{pmatrix} X_1 & Y_1 & 1 \\ X_2 & Y_2 & 1 \\ X_3 & Y_3 & 1 \end{pmatrix} \times \begin{pmatrix} D \\ E \\ F \end{pmatrix}$$

The unknown can be calculated using the equations that follow.

Equation 21

$$\begin{pmatrix} A \\ B \\ C \end{pmatrix} = \boldsymbol{M}^{-1} \begin{pmatrix} X_{D1} \\ X_{D2} \\ X_{D3} \end{pmatrix}$$

Equation 22

$$\begin{pmatrix} D \\ E \\ F \end{pmatrix} = \boldsymbol{M}^{\ 1} \begin{pmatrix} Y_{D1} \\ Y_{D2} \\ Y_{D3} \end{pmatrix}$$

where

$$\boldsymbol{M} = \begin{pmatrix} X_1 & Y_1 & 1 \\ X_2 & Y_2 & 1 \\ X_3 & Y_3 & 1 \end{pmatrix}$$

and

$$\boldsymbol{M}^{-1} = \frac{1}{\det(\boldsymbol{M})} \mathrm{Adj}(\boldsymbol{M})$$

To increase accuracy, more points can be used to solve the equation. An example 5-point calibration is shown below. Similar to 3-point calibration, a matrix representation is formed:

Equation 23

$$\begin{pmatrix} X_{D1} \\ X_{D2} \\ X_{D3} \\ X_{D4} \\ X_{D5} \end{pmatrix} = \boldsymbol{M} \times \begin{pmatrix} A \\ B \\ C \end{pmatrix}$$

Equation 24

$$\begin{pmatrix} Y_{D1} \\ Y_{D2} \\ Y_{D3} \\ Y_{D4} \\ Y_{D5} \end{pmatrix} = \boldsymbol{M} \times \begin{pmatrix} D \\ E \\ F \end{pmatrix}$$

where

$$\boldsymbol{M} = \begin{pmatrix} X_1 & Y_1 & 1 \\ X_2 & Y_2 & 1 \\ X_3 & Y_3 & 1 \\ X_4 & Y_4 & 1 \\ X_5 & Y_5 & 1 \end{pmatrix}$$

Equation 23 and *24* are solved by multiplying both sides by (M^TxM)-1x M^T to get:

Equation 25

$$\begin{pmatrix} A \\ B \\ C \end{pmatrix} = \left(\boldsymbol{M}^{T} \times \boldsymbol{M}\right)^{-1} \times \boldsymbol{M}^{T} \times \begin{pmatrix} X_{D1} \\ X_{D2} \\ X_{D3} \\ X_{D4} \\ X_{D5} \end{pmatrix}$$

Equation 26

$$\begin{pmatrix} D \\ E \\ F \end{pmatrix} = \left(\boldsymbol{M}^{T} \times \boldsymbol{M}\right)^{-1} \times \boldsymbol{M}^{T} \times \begin{pmatrix} Y_{D1} \\ Y_{D2} \\ Y_{D3} \\ Y_{D4} \\ Y_{D5} \end{pmatrix}$$

To simplify, the values of the unknowns are calculated as follows:

Equation 27

$$\begin{aligned} A &= d_{X1} / d \\ B &= d_{X2} / d \\ C &= d_{X3} / d \\ D &= d_{Y1} / d \\ E &= d_{Y2} / d \\ F &= d_{Y3} / d \end{aligned}$$

where

Equation 28

$$d = 5\times\left(\alpha\times\beta-\chi^2\right)+2\times\chi\times\varepsilon\times\phi-\alpha\times\phi^2-\beta\times\varepsilon^2$$
$$d_{X1} = 5\times(k_X\times\beta-l_X\chi)+\phi\times(l_X\times\varepsilon-k_X\times\phi)+m_X\times(\chi\times\phi-\beta\times\varepsilon)$$
$$d_{X2} = 5\times(l_X\times\alpha-k_X\times\chi)+\varepsilon\times(k_X\times\phi-l_X\times\varepsilon)+m_X\times(\chi\times\varepsilon-\alpha\times\phi)$$
$$d_{X3} = k_X\times(\chi\times\phi-\beta\times\varepsilon)+l_X\times(\chi\times\varepsilon-\alpha\times\phi)+m_X\times\left(\alpha\times\beta-\chi^2\right)$$
$$d_{Y1} = 5\times(k_Y\times\beta-l_Y\chi)+\phi\times(l_Y\times\varepsilon-k_Y\times\phi)+m_Y\times(\chi\times\phi-\beta\times\varepsilon)$$
$$d_{Y2} = 5\times(l_Y\times\alpha-k_Y\times\chi)+\varepsilon\times(k_Y\times\phi-l_Y\times\varepsilon)+m_Y\times(\chi\times\varepsilon-\alpha\times\phi)$$
$$d_{Y3} = k_Y\times(\chi\times\phi-\beta\times\varepsilon)+l_Y\times(\chi\times\varepsilon-\alpha\times\phi)+m_Y\times\left(\alpha\times\beta-\chi^2\right)$$

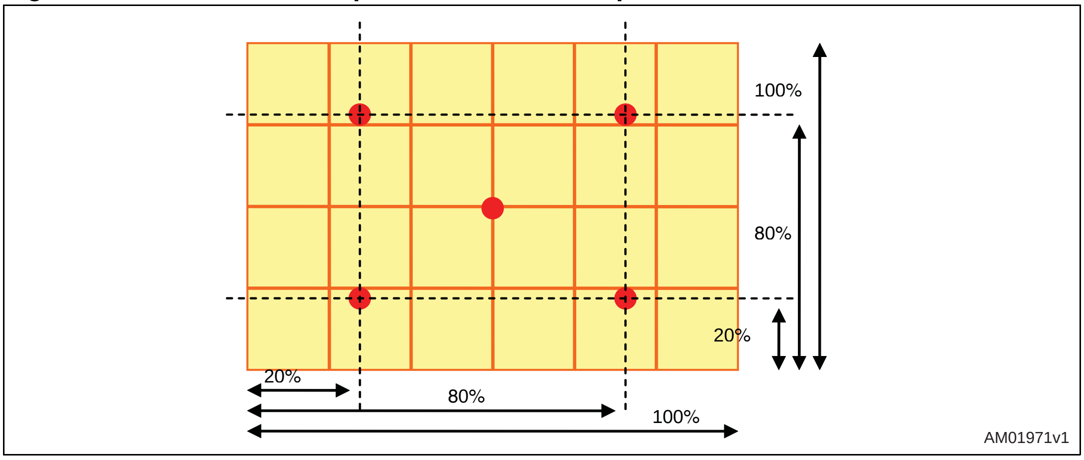
$$\alpha=\sum_{k=1}^{5}X_k^2 \quad \beta=\sum_{k=1}^{5}Y_k^2 \quad \chi=\sum_{k=1}^{5}X_k\times Y_k \quad \varepsilon=\sum_{k=1}^{5}X_k \quad \phi=\sum_{k=1}^{5}Y_k$$

$$k_X=\sum_{k=1}^{5}X_k\times X_{Dk} \quad l_X=\sum_{k=1}^{5}Y_k\times X_{Dk} \quad m_X=\sum_{k=1}^{5}X_{Dk} \quad k_Y=\sum_{k=1}^{5}X_k\times Y_{Dk}$$

$$l_Y=\sum_{k=1}^{5}Y_k\times Y_{Dk} \quad m_Y=\sum_{k=1}^{5}Y_{Dk}$$

The recommended points to use in 5-point calibration are shown in *Figure 6*.

Figure 6. Recommended point locations for 5-point calibration



3 Revision history

Table 4. Document revision history

Date	Revision	Changes
26-Jan-2009	1	Initial release.