Multi-Touch Points Detection for Capacitive Touch Panel

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***Abstract*—We consider the detection of multiple touch points for capacitive touch panel systems under Gaussian noise. We propose an algorithm that reduces the noise-induced detection error and improves the detection accuracy with partial touch signal information. The proposed algorithm is based on the likelihood ratio test, and utilizes the touch signal features, such as the local maximum, the range of touch magnitude, and the consecutive occurrence of touch locations, to first detect touch points and then calculates the real touch coordinates based on the weighting average technique. Simulation demonstrates the improved performance of the proposed algorithm.**

I. Introduction

The touch-based human-machine interfaces are widely used in consumer electronic devices to reduce the cognitive burden of computer operations. The multi-touch equipments allow users to interact with the computer by using multiple fingers. One technology that can realize the multi-touch points detection is the capacitive touch panel [1], [2]. Due to its low cost and small size, the capacitive touch panel has attracted much attention and has become a basic configuration of modern electronic products.

One drawback of the capacitive touch panel is its high sensitivity to the surroundings [3], [4]. The change of the ambient temperature, moisture, or electrical field leads to large noise and thus the sensing accuracy deficit. Many research works study multi-touch detection on the capacitive touch panel without taking into account the noise-induced detection error. The work of [5], [6] focuses on the reduction of hardware complexity by a compressive sensing based approach. The work of [7] addresses the sensing speed and proposes an algorithm to detect the presence of touch. In [8], the authors propose a method to distinguish fingers on the touch panel for a specific application purpose. Although the works presented in [9], [10] consider the robust design to reduce the noise influence, the design is based on the analog circuits.

To the best of our knowledge, the design problem of a multi-touch points detection algorithm that considers the noise-induced error detection and can be implemented by digital circuits has not been studied before. This work aims at proposing a practical solution for the capacitive touch panel system. We propose a method that first estimates signals of each sensor in the touch panel with partial touch signal information. The likelihood ratio test (LRT) and the touch signal features, such as the local maximum, the range of touch magnitudes, and the consecutive occurrence of touch locations, are then used to determine the valid touch points. The weighting average technique is then applied on the valid touch points to obtain the real touch coordinates. We conduct computer simulations to demonstrate the performance of the proposed algorithm.

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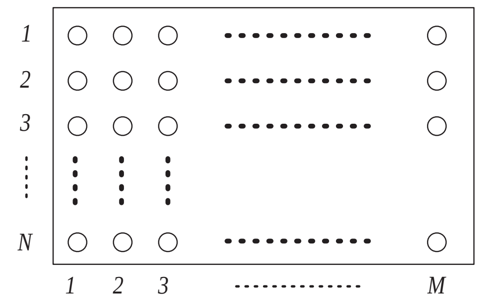

Fig. 1. An array of sensors on the touch panel.

The rest of this paper is organized as follows. In Section II, we describe the model of the capacitive touch panel system and the hypothesis test problem. In Section III, we propose an algorithm that reduces the noise-induced detection error for multi-touch points detection. Simulation results are presented in Section IV. Section V concludes this work.

II. System Model

We consider a touch panel consisting of an array of sensors with N rows and M columns as shown in Fig. 1. We assume that as a finger touches the panel, a sensor that is closest to the finger and the surrounding $(K-1)$ sensors will measure this finger touch. Fig. 2(a) shows an example where a finger touches the sensor (m, n) and the total number of active sensors as a result of this finger touch is $K = 9$. We label these sensors by S_1 to S_9 as shown in Fig. 2(b), and rearrange them in the vector form as shown in Fig. 2(c). The touch signal vector can be expressed as $c \cdot \mathbf{s}$, where $c \in \mathbb{R}_+$ is a positive touch magnitude and $\mathbf{s} \in \mathbb{R}_+^9$ is a 9×1 positive touch shape vector with $\mathbf{s}^T\mathbf{s} = 1$. In general, since K sensors are affected by a finger touch, the dimension of the touch shape vector is $K \times 1$, i.e., $\mathbf{s} \in \mathbb{R}_+^K$.

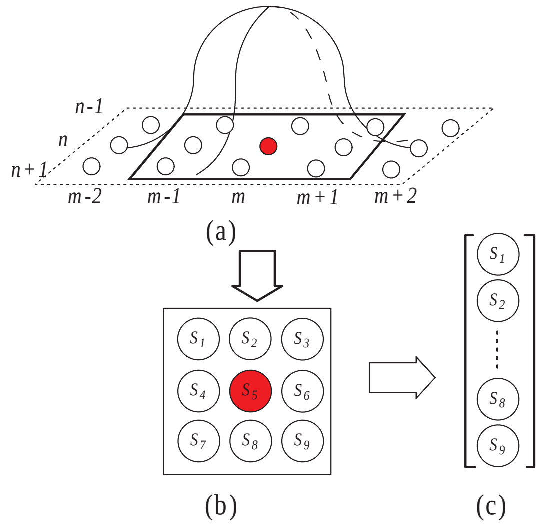

Fig. 2. An example of touch signal where the actual touch is on the sensor (m, n): (a) 3×3 sensors being affected by a touching finger with 2D Gaussian distribution of touch signal, (b) labeling the 3×3 sensors, and (c) rearranging the sensors in a vector form.

In this paper, we assume that for different finger touch the touch signal vector is different; specifically, we assume that for any finger touch the touch shape vector $\mathbf{s}$ is identical while the touch magnitude c varies in the range $(\alpha_{\min}, \alpha_{\max})$. When a finger touch locates at the sensor (m, n), the measurements by the sensor (m, n) and its surrounding $(K-1)$ sensors can be expressed as the following vector

$$\mathbf{r}_{m,n} = c_{m,n}\,\mathbf{s} + \mathbf{v}_{m,n}, \quad \begin{aligned} m &= 1, \ldots, M \\ n &= 1, \ldots, N \end{aligned} \tag{1}$$

where $\mathbf{v}_{m,n} \in \mathbb{R}^K$ is an additive Gaussian noise vector with zero mean and covariance matrix $\sigma^2\mathbf{I}$.

It is known that signal detection in background noise can be formulated through the Bayes theory [11] of hypothesis testing. Hence, we consider the detection problem as the following binary hypothesis test

$$\left\{ \begin{array}{ll} \mathcal{H}_1: & \mathbf{r}_{m,n} = c_{m,n}\,\mathbf{s} + \mathbf{v}_{m,n} \\ \mathcal{H}_0: & \mathbf{r}_{m,n} = \mathbf{v}_{m,n} \end{array} \right. . \tag{2}$$

The hypothesis $\mathcal{H}_0$ corresponds to measuring noise only and thus there is no touch signal; the hypothesis $\mathcal{H}_1$ corresponds to measuring a deterministic touch signal in the background noise. Since $\mathbf{v}_{m,n}$ is Gaussian and $c_{m,n}\mathbf{s}$ is deterministic, the probability density functions (pdfs) of the measurement vector in two hypotheses $\mathcal{H}_1$ and $\mathcal{H}_0$ can respectively be written as

$$\left\{ \begin{array}{l} p_{\mathbf{r}}(\mathbf{r}_{m,n}\,|\mathcal{H}_1) = \dfrac{1}{(2\pi)^{K/2}\sigma^K} \times \\ \qquad\qquad \exp\left(-\dfrac{1}{\sigma^2}(\mathbf{r}_{m,n} - c_{m,n}\mathbf{s})^T(\mathbf{r}_{m,n} - c_{m,n}\mathbf{s})\right) \\ p_{\mathbf{r}}(\mathbf{r}_{m,n}\,|\mathcal{H}_0) = \dfrac{1}{(2\pi)^{K/2}\sigma^K} \exp\left(-\dfrac{1}{\sigma^2}\mathbf{r}_{m,n}^T\mathbf{r}_{m,n}\right) \end{array} \right. . \tag{3}$$

Our goal is to make a decision on whether there is a finger touch at the sensor (m, n) based on the measurement vector $\mathbf{r}_{m,n}$. The likelihood ratio test (LRT) can be used as a decision rule and is given by

$$\Lambda(\mathbf{r}_{m,n}) = \frac{p_{\mathbf{r}}(\mathbf{r}_{m,n}\,|\mathcal{H}_1)}{p_{\mathbf{r}}(\mathbf{r}_{m,n}\,|\mathcal{H}_0)} \underset{\mathcal{H}_0}{\overset{\mathcal{H}_1}{\gtrless}} \lambda \tag{4}$$

where λ is a detection threshold. The value of λ determines the detection behavior. If λ is too small, $\mathcal{H}_1$ may be chosen in the absence of a touch signal and the probability of false alarm increases. If λ is too large, $\mathcal{H}_0$ may be chosen in the presence of a touch signal and the probability of miss increases. Substituting (3) in (4) and simplifying, we have

$$\mathbf{s}^T\mathbf{r}_{m,n} \underset{\mathcal{H}_0}{\overset{\mathcal{H}_1}{\gtrless}} \underbrace{\frac{\sigma^2}{2c_{m,n}}\log\lambda + \frac{c_{m,n}}{2}}_{T} \tag{5}$$

where $\log(\cdot)$ denotes the natural logarithm. As can be seen from (5), the decision rule is to compare the inner product of the touch shape vector $\mathbf{s}$ and the measurement vector $\mathbf{r}_{m,n}$ with the threshold T.

III. Proposed Detection Algorithm

The analysis in Section II is based on the assumption that the touch magnitude $c_{m,n}$ is known. In practice, the touch magnitude is unknown *a priori* and thus the LRT in (4) cannot be used directly. We will propose a method to estimate $c_{m,n}$ in this section. By the estimated magnitude, the LRT and the touch signal features are then used to determine the touch points. The following assumptions are used in this section: 1) the touch magnitude $c_{m,n}$ is only known in the range $(\alpha_{\min}, \alpha_{\max})$ but its exact value is unknown, and 2) the touch shape vector $\mathbf{s}$ is known. We propose a practical algorithm for multi-touch points detection on the touch panel.

It is known that a finger touch located at the sensor (m, n) affects its surrounding $(K-1)$ sensors. In the presence of the background noise, the touch magnitude of the sensor (m, n) should first be estimated based on the K measurements in (1). The magnitude estimation problem can be regarded as maximizing the pdf of $\mathcal{H}_1$ with respect to $c_{m,n}$. By the first equation of (3), it can be shown that the touch magnitude estimate is given by

$$\hat{c}_{m,n} = \frac{\mathbf{s}^T\mathbf{r}_{m,n}}{\mathbf{s}^T\mathbf{s}} = \mathbf{s}^T\mathbf{r}_{m,n} \tag{6}$$

where we have used the fact that $\mathbf{s}^T\mathbf{s} = 1$. It is noted that as the sensor measures noise only (i.e., $\mathcal{H}_0$), the estimated magnitude in (6) is small and close to zero.

For the sensor closest to the finger touch, its magnitude is the largest compared with the neighborhood. Hence, after estimating the magnitudes of all sensors, the sensors whose magnitudes are local maximum and in the range $(\alpha_{\min}, \alpha_{\max})$ are chosen for further processing. Also, since the estimated magnitude of the sensor (m, n) is obtained, the LRT in (5) can be used with $c_{m,n}$ replaced by $\hat{c}_{m,n}$ to decide whether or not the sensor belongs to $\mathcal{H}_1$. By (5) and (6), the decision rule can be simplified as

$$\hat{c}_{m,n} \underset{\mathcal{H}_0}{\overset{\mathcal{H}_1}{\gtrless}} \sqrt{\sigma^2 \log \lambda} \tag{7}$$

where we use the fact that $\hat{c}_{m,n} \in \mathbb{R}_+$. Hence, the sensor (m, n) can be regarded as a candidate of touch points if its estimated magnitude satisfies: 1) $\hat{c}_{m,n}$ is a local maximum, 2) $\hat{c}_{m,n}$ is in the range $(\alpha_{\min}, \alpha_{\max})$, and 3) $\hat{c}_{m,n} \geq \sqrt{\sigma^2 \log \lambda}$. We save the locations of the candidates of touch points in the touch candidate set $\Omega(t)$. In practice, since a valid touch occurs at least two consecutive sampling time, we compare the touch candidate set at time t with the previous touch candidate set at time $t-1$ for determining valid touch points. That is, the sensor (m, n) is regarded as a valid touch point if

$$(m, n) \in \Omega(t-1) \quad \text{and} \quad (m, n) \in \Omega(t). \tag{8}$$

For the candidates of the touch points that are not detected in two consecutive sampling time, they are regarded as the false alarm detection caused by noise and thus not valid touch points.

For the valid touch points, we then determine the real touch coordinates by the weighting average technique [12], [13]. More precisely, assume that the estimated magnitudes of the valid touch point and its neighborhood are $\hat{c}_{m_1,n_1}, \ldots, \hat{c}_{m_9,n_9}$ and the corresponding locations are $(m_1, n_1), \ldots, (m_9, n_9)$, the real touch coordinates (x, y) can be evaluated by

$$\begin{aligned} x &= \frac{\sum_{i=1}^{9} \hat{c}_{m_i,n_i} m_i}{\sum_{i=1}^{9} \hat{c}_{m_i,n_i}} \\ y &= \frac{\sum_{i=1}^{9} \hat{c}_{m_i,n_i} n_i}{\sum_{i=1}^{9} \hat{c}_{m_i,n_i}}. \end{aligned} \tag{9}$$

Remarks: Although the total number of active sensors as a result of a finger touch is K, the signal strength measured by a sensor is inversely proportional to the distance between the sensor and the touch location. Hence, we only use the measurements of the 9 sensors, which are closest to the finger, to evaluate the touch coordinates since their measured values caused by the finger touch are large and thus the noise influence is small.

We summarize the proposed algorithm for the multi-touch points detection in Fig. 3.

IV. Simulation Results

In this section, we use numerical simulations to verify the proposed algorithm described in Section III. In the simulations, we consider a touch panel consisting of an array of sensors with $N = 20$ and $M = 30$. The range of the touch magnitude is set as $(150, 800)$. The sensor located at $(11, 11)$ is touched and the touch signal affects its neighbor 5×5 sensors, i.e., we set $K = 25$. The correct detection is defined to be the decision of the real touch coordinates (x, y) being located in the following region: $10.5 \leq x \leq 11.5$ and $10.5 \leq y \leq 11.5$. If the real touch coordinates locate outside this region, it is regarded as the false alarm.

We define the detection probability P_D and the false alarm probability P_{FA} as the ratios of the correct detection and

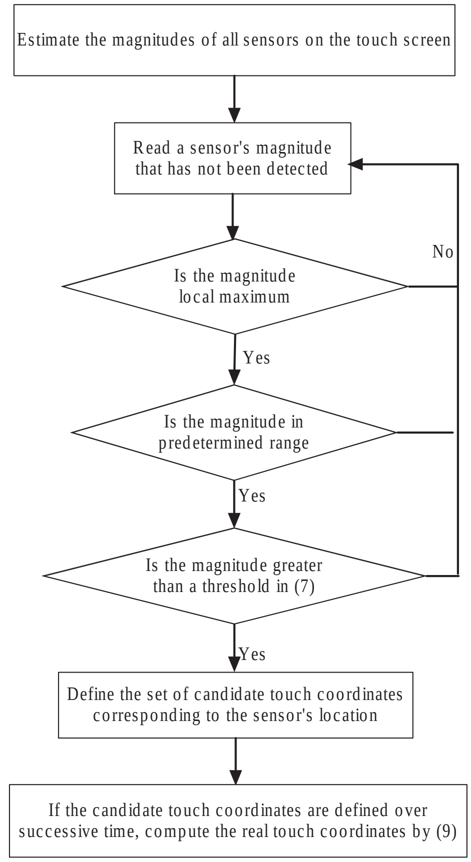

Fig. 3. Flowchart of the proposed algorithm.

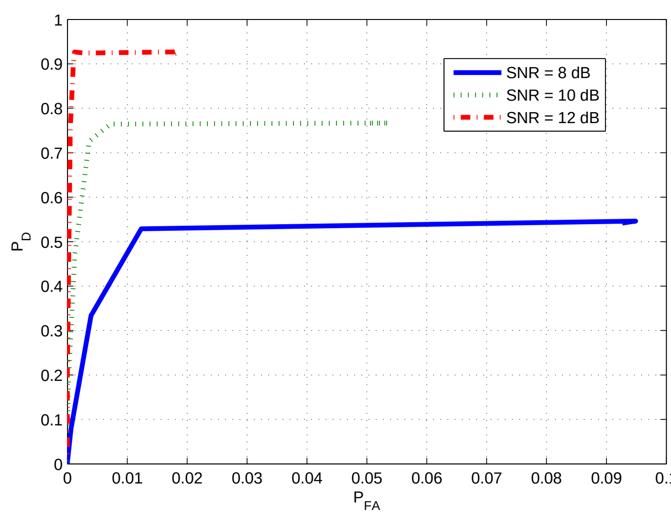

Fig. 4. P_D versus P_{FA} for different SNR.

the false alarm, respectively, over 10^5 simulation runs. Fig. 4 shows P_D versus P_{FA} with λ from 0 to ∞ for different signal-to-noise ratio (SNR). We can see that for SNR$= 8$ dB, the best achievable P_D is 0.52 while the worst P_{FA} is 0.095. From this figure, we also see that as the SNR increases, P_D increases and P_{FA} decreases for a fixed λ.

We define the error probability as the ratio that the final

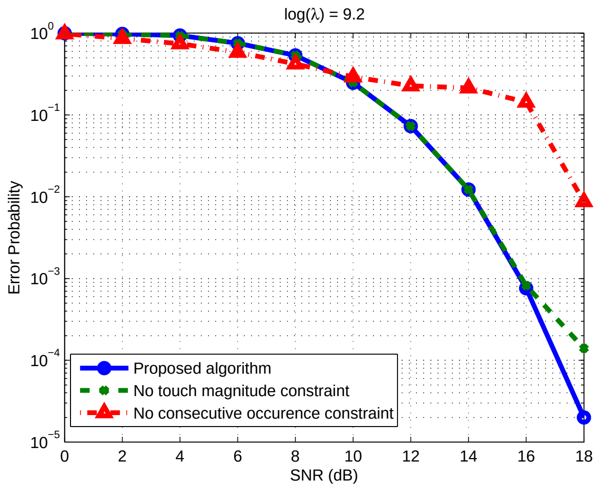

Fig. 5. The error probability versus SNR for different algorithm configurations.

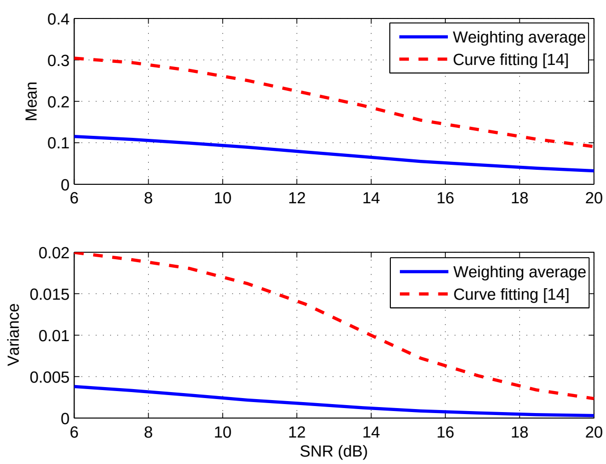

Fig. 6. Touch accuracy test.

decision includes correct detection and no false alarm occurs over 10^5 simulation runs. In Fig. 5, we compare the proposed algorithm with and without the touch magnitude constraint $(\alpha_{\min}, \alpha_{\max})$ and the consecutive occurrence constraint in (8). The figure shows that with (8), although the performance is slightly worse than that without (8) in low SNR, the error probability decreases significantly as SNR > 10 dB. We also see that with the touch magnitude constraint, the performance improves after SNR > 16 dB compared to the algorithm without the touch magnitude constraint.

In Fig. 6, we compare two coordinates evaluation methods, one based on curve fitting [14] and one based on the weighting average method in (9). The computed coordinates are compared with the actual touch point $(11, 11)$ and the error distance $d = \sqrt{(x-11)^2 + (y-11)^2}$ is calculated. The figure shows the mean and variance of d over 10^4 correct detection instances. As can be seen from this figure, the weighting average method is more robust that the curve fitting method over all SNR values.

V. Conclusion

We have studied the detection of multi-touch points for capacitive touch panel systems in this paper. With partial touch signal information, the LRT cannot be used directly in our problem. The proposed method first estimates the magnitudes of each sensor by local information. By local maximum test, touch range test, and LRT of the estimated magnitude, the sensor is decided whether or not it is a candidate of touch points. To reduce the noise-induced detection error, we compare the candidate set over two consecutive time and determine the valid touch points, which are used to evaluate the real touch coordinates by the weighting average method.

Our future investigation includes a study of the choice of the threshold λ that minimizes the error probability. It is also a worthwhile study to estimate the range of the touch magnitude $(\alpha_{\min}, \alpha_{\max})$ by techniques such as training and machine learning.

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