동시구동 및 순차센싱을 이용한 대형 정전용량 터치스크린용 고속 센싱 기법

(A Fast Sensing Method using Concurrent Driving and Sequential Sensing for Large Capacitance Touch Screens)

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요 약

최근 스마트폰의 발달과 더불어 대형 TV, 의료용 장비 및 전자 칠판에도 터치스크린의 수요가 급증하고 있다. 스크린 사이즈가 증가함에 따라 고해상도를 위한 뛰어난 성능을 갖추기 위해 시간이 소요될 수 있어 터치감지 시간이 길어지는 문제가 되고 있다. 본 논문에서는 이러한 문제를 해결하기 위하여 새로운 드라이빙 및 센싱 기법을 제안한다. 이 기법은 differential 드라이빙 방법으로 2 단계로 수행되며, 먼저 고속 센싱 프로세스를 통해 터치가 발생된 센싱 라인들을 우선 대략적으로 도출한 후 정확한 터치 위치를 측정하기 위해 센싱 라인에서만 원하는 라인을 탐색하는 방법을 사용하였다. 이 방법을 사용하면 터치 패널의 frame refresh rate를 향상시킬 수 있다. 제안된 기법은 기존 기법의 frame scan rate를 8.4배 향상시킨다.

Abstract

Recently the demand for projected capacitance touch screens is sharply growing especially for large screens for medical devices, PC monitors and TVs. Large touch screens in general need a controller of higher complexity. They usually have a larger number of driving and sensing lines, and hence it takes longer to scan one frame for touch detection leading to a low frame scan rate. In this paper, a novel touch screen control technique is presented, which scans each frame in two steps of simultaneous multi-channel driving. The first step is to drive all driving lines simultaneously and determine which sensing lines have any touch. The second step is to sequentially rescan only the touched sensing lines, and determine exact positions of the touches. This technique can substantially increase the frame scan rate. This technique has been implemented using an FPGA and an AFE board, and tested using a commercial 23-inch touch screen panel. Experimental results show that the proposed technique improves the frame scan rate by 8.4 times for the 23-inch touch screen panel over conventional methods.

Keywords: Touch screen, Mutual-Capacitive, Touch Screen Controller, Multi-touch

I. Introduction

Touch screen panels (TSPs) are used to detect human touch or a special pen by changing one of their physical properties. Nowadays, capacitive touch screens are the most popular type among many TSP types. There are different types of capacitive TSPs:
surface capacitive and projected capacitive types. The projected capacitive panels are further classified as mutual capacitance, and self-capacitance types. For medium and small-size TSPs for mobile products, mutual capacitive-type TSPs have superior visibility and durability, and also provide multi-touch functions. Nowadays projected mutual capacitance TSPs are most widely used for medium to small-sized mobile products, and are also increasingly adopted for large PC monitors and TV screens. They have superior visibility and durability and also exhibit a multi-touch function. In mutual capacitance TSPs, touch detection is determined by measuring the change in the mutual capacitance.

Fig. 1 shows a part of projected mutual capacitance touch screen panel electrodes driven by a sequence of pulses which results in a staircase signal after integration of the output signal. This technique is the conventional touch screen controller system. Touch screen panel structure used in Fig. 1 uses a cross-line structure with large plates to magnify the value of the mutual capacitance to get better touch detection results. Different ways of driving and sensing have been examined through previous research efforts in order to improve signal to noise ratio (SNR) and so avoid incorrect touch detection result. Mutual capacitance touch screen panels are susceptible to noise, so much of research has been focused on how to reduce the noise and increase the touch signal strength.

While there are software algorithm approaches, many papers proposed circuit hardware approaches to address the noise reduction problem.

In this paper, we propose a new approach based on both hardware and software using concept of differential driving for faster touch detection. Most of previous research efforts have been focused on a small touch screen controllers. As the size of TSPs grows, in general, the number of driving (TX) lines and sensing (RX) lines tends to increase to keep high resolution of touch detection. It becomes therefore, difficult to control a large TSP because of frame scan rate is much lower than required. Our solution also provides an efficient method of concurrent driving and selective sensing, which allows frame scan rate improvement and effective noise cancellation.

One of the methods to cancel supply noise is using differential driving technique. In our method, two adjacent cells are driven with opposite polarity signals to cancel out supply noise. This idea is based on the high probability of affecting two adjacent cells with opposite noise level.

This paper is organized as follows. Section II introduces the proposed touch screen controller system. Section III presents simulation results of the controller system. Finally conclusions are presented in section IV.

II. Touch Screen Controller System

Various scanning techniques of touch screen controllers have been published to improve their noise immunity and increase the SNR. However few scanning techniques have been reported in literature to efficiently improve the frame scan rate of large TSPs.

Large touch screen panels usually have a large...
number of driving (TX) and sensing (RX) lines in order to improve touch detection resolution. This imposes high burden on touch screen controller design. The time required to scan one frame grows along with the number of TX and RX lines in most touch screen control methods. However most touch screen controller systems have a target frame scan rate that they must satisfy to ensure touch detection quality which is usually in the range of 100Hz~200Hz.

The proposed touch screen controller provides an effective solution with a very high scan rate for large touch screen panels. It consists of three components driving TX lines, sensing RX lines, and running detection algorithm software on the sensed data and send touch position data to PC. A novel driving and scanning technique is introduced, which reduces the frame scan time. The controller can be used for touch screen panels of different sizes, fabricated with various materials and various patterns. Fig. 2 shows our system implementation to drive a commercial 23" TSP with 44 TX lines and 78 RX lines.

1. Differential driving and differential sensing

Fig. 3(a) shows a differential driving controller architecture and their output signal output, while Fig. 3(b) illustrates a differential sensing controller case. Differential sensing can be conducted by applying a series of pulses to one TX line and taking the difference between two adjacent RX lines in order to sense two adjacent cells in the same raw. On the other hand, differential driving can be conducted by applying opposite polarity pulses to two adjacent TX lines and sensing one RX line. Hence two adjacent cells in the same column are sensed at the time.

Differential sensing removes the noise affecting two adjacent cells in the same row (TX line) which is ambient noise. Differential driving often reduces the frame scan period.

2. Proposed concurrent driving technique

The proposed touch screen sensing scheme consists of two steps to scan one frame of touch screen panel. In the first step, all TX lines (rows) are
concurrently driven by opposite polarity pulses, which is described by Fig. 4(a). This step determines the touched RX lines by observing the output of each RX line.

The idea behind this technique is to cancel the common mode signal while leaving only the differential signal by applying opposite excitation pulses to every adjacent cells in the same RX line. This concurrent driving results in zero output in case of no touch while giving non-zero output if any cell on the RX line is touched. Fig. 5 shows the output of RX line in the touched and untouched cases. The second step is to sequentially scan each pair of two adjacent cells in only the touched RX lines as shown in Fig. 4(b).

The proposed scheme eliminates the needs for scanning all cells every frame which is the major drawback of conventional schemes, and so it can improve the frame scan rate.

For an example touch screen of TX x RX = 44 x 78 lines, a conventional sensing schemes require \((3432 \Delta t)\) seconds where \(\Delta t\) is the time for scanning one cell. The proposed scheme, on the other hand, needs only \((78\Delta t + n \times 22\Delta t)\) where \(n\) is the number of RX lines that are sensed as touched lines.

Here, the 1st term \(78\Delta t\) is the time consumed by the 1st step which scans all RX lines to find touched lines. The 2nd term \(n \times 22\Delta t\) is the time consumed by the 2nd step which scans all cells for each of the touched RX lines.

Consider an example where five fingers are touching different RX lines. Assuming that one touch point affects 3 RX lines on average, the number of affected RX lines is 15. Then the proposed scheme has a total scanning time of \(78\Delta t + 15 \times 22\Delta t = 408\Delta t\). This is an improvement of 8.4 times compared with the conventional scheme.

For the proposed scheme, a generalized form of the frame scan rate (FSR) is given by:

\[
FSR_{\text{proposed}} = \frac{1}{(\text{no.of RX}+\frac{n}{2}\times\text{no.of TX})\Delta t} 
\]

while the frame scan rate for the conventional scheme is given by:

\[
FSR_{\text{conventional}} = \frac{1}{(\text{no.of RX}\times\text{no.of TX})\Delta t} 
\]

The proposed scheme can employ either a differential sensing circuit or a single-ended sensing circuit. In this paper, we assume that the sensing
The sensing circuit has a single ended integrator that senses the output of each RX line (the entire column in Fig. 4) and results in a stair case output as shown in Fig. 5. The proposed scheme can substantially speed up the overall sensing process allowing a very fast frame scan rate. It, therefore, is well suited for large touch screens.

3. Touch detection algorithm
The proposed scheme is implemented by a touch detection algorithm as illustrated by the flow diagram in Fig. 6. In this algorithm, all RX lines are scanned sequentially with all TX line driven concurrently through the first step. It then drives each pair of TX lines sequentially by opposite pulses until all touched RX lines are scanned.

The flow diagram of Fig. 6 starts by driving all TX lines concurrently with opposite polarity pulses and reads one RX line at a time. Through this step, each RX line RXₙ is marked as touched or untouched. Once all the touched RX lines are determined, the second step starts by selecting the first touched RX line RX₀, and drive the first TX pair (TX₀, TX₀). Each cell on the selected RX line is marked based on the integrator’s output. A positive integrator output indicates that the first cell TX₀ of the TX pair is touched, while a negative integrator output indicates that the second cell TX₁ is touched. The above process is repeated for all TX pairs to scan all touched RX lines. Once all the touched RX

<table>
<thead>
<tr>
<th>RX line output</th>
<th>Signal after integrator</th>
<th>Output value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Even cell is touched</td>
<td>![Even cell diagram]</td>
<td>V</td>
</tr>
<tr>
<td>Odd cell is touched</td>
<td>![Odd cell diagram]</td>
<td>-V</td>
</tr>
<tr>
<td>No touched cells</td>
<td>![No touched cells diagram]</td>
<td>0</td>
</tr>
</tbody>
</table>
lines are scanned with all TX pairs concurrent driven, all touched cells (touch positions) are extracted.

The ambient noise on TSP, however, often makes the integrator output deviate from the ideal V and V- values. In the evaluation of the integrator outputs, we compare the outputs with certain thresholds to effectively determine each cell as touched or untouched under practical ambient noise signals.

### III. Results and Discussions

The results presented in this section is measured from our system implementation with FPGA and AFE board as shown in Fig. 2. We have also implemented the proposed scheme in a silicon chip, which was fabricated in a TSMC CMOS 0.18um process in a Multi-Project Wafer MPW. We plan to present the result of this chip, when the chip is available.

1. **Scan rate improvement**

As described above, the proposed touch detection technique employs a fast scan algorithm, unlike a conventional method which repeatedly scans all cells exhaustively. The conventional method needs a total time of (no. of RX × no. of TX)\(\Delta t\) seconds to finish a scan of one frame, where \(\Delta t\) represents the time required to scan one cell and it is determined by the frequency of driving signals and the number of integrations required to get a target output. On the other hand the proposed technique takes (no. of RX)\(\Delta t\) seconds to finish the first scan step and \((n/2 \times \text{no. of TX})\Delta t\) seconds to finish the second scan step, where \(n\) is the number of touched RX lines found.

As shown in Fig. 7 the frame scan rate for the proposed technique is substantially improved by 8.4 times for 23 inches touch screen panel and 3.62 times for 10 inches touch screen panel compared with a conventional method assuming that one touch point affects three adjacent RX lines. In this experiment, \(\Delta t\) (the time required to scan one cell) is configured as 1.6us. We also configured the input signal frequency as 5MHz. The number of integrations of the sensing circuit is configured as 8 integrations to achieve practical detection performance.

2. **Output voltage difference**

In ideal case, differential driving and differential sensing give an integration output of 0V when there is no touch event over the two adjacent cells. In real TSPs, it, however, has a non-zero integration output.
As shown in Fig. 8(b), the integration output is larger than zero. This is due to the fact that the signals propagate through two different paths as illustrated by Fig. 8(a). While both paths are quite similar, there is an additional RC circuit stage in the path from TX0 compared to the path from TX1. This additional RC circuit causes a non-zero difference in voltage as shown in Fig. 8.

Fig. 9 shows the integrator output with all TX lines driven with opposite polarity pulses in touch and untouch events. In the case of driving all TX lines at the same time, the non-zero outputs caused by the differential driving of two TX lines with (a) Schematic model of a touch screen panel showing the difference between the two signal paths. (b) Integrator output with 2 differential TX inputs having the same amplitude. (c) Integrator output with 2 differential TX input with calibration.
difference of every two adjacent paths, tend to accumulate and result in a high output voltage as shown in Fig. 9 (a).

The proposed calibration method is to apply different levels of input signals to compensate the difference in signal paths. In this way, the signals that propagate in longer paths are assigned with larger amplitude. Hence the proposed scheme ensures that the integration output is approximately zero in untouched case as shown in Fig. 9 (b).

IV. Conclusions

We have presented a new driving and sensing scheme for projected mutual capacitance touch screens. We proposed a two-step algorithm to reduce the time required to finish one frame scan. Using simulation experiments with realistic TSPs of various size, we have shown that the proposed scheme can improve the frame scan rate by 8.4 times for 23” TSP compared to a conventional scheme. The proposed scheme tends to provide a faster frame scan rate as the TSP size grows.

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