Signal Processing for Pen and Touch Sensors

May 31, 2021
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Wacom
Outline

1. Pen and Touch User Interface
2. EMR (Electro-Magnetic Resonance) Sensing Technology
3. Capacitive Sensing Technology
   - Principle
   - SNR Enhancement
   - Noise Immunity
   - Sensor Requirement
   - Passive Pen
   - Active Pen
4. Latest Technical Challenges
Pen and Touch User Interface
Professional Creation Support

Industry Design

Games

Animation

Movie Production
Pen Tablet Products for Creative Users

wacom® One

wacom® Intuos Pro

wacom® Cintiq Pro

BAMBOO® ink

BAMBOO® Slate

BAMBOO® Folio
Digital Signature System

Citibank, Korea

Wacom Clipboard

Signature Tablets

Lalaport, Mitsui Fudosan Retail Management, Japan
Wacom Ink Layer Language

Pen movement
while hovering

Pen pressure

Shape of stroke
- Direction
- Curvature

X, Y Time data
- Acceleration
- Speed
Pen and Ink Solutions for Smartphones, Tablet, PC, Digital Stationery, etc.
Electro-Magnetic Resonance Sensing Technology
EMR: Sensing Principle

- No Battery in the pen

https://tablet.wacom.co.jp/what/news-img/W8002basis.pdf
EMR: Sensing Signals

https://tablet.wacom.co.jp/what/news-img/W8002basis.pdf
EMR: Pen Position Sensing

https://tablet.wacom.co.jp/what/news-img/W8002basis.pdf
EMR: Pen Pressure, Side Switch, Eraser

[An Example]

https://tablet.wacom.co.jp/what/news-img/W8002basis.pdf
EMR: Sensor Stack-up

https://tablet.wacom.co.jp/what/news-img/W8002basis.pdf
Capacitive Sensing Technology
- Principle
- SNR Enhancement
- Noise Immunity
- Sensor Requirement
- Passive Pen
- Active Pen
Mutual Capacitance Sensing

Mutual Capacitance Sensor Pattern

【Diamond】

【Stripe】

Sensing Control Circuit

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How to estimate the capacitance

1. Charge Integration (Charge to Voltage Conversion)

\[ V_{\text{out}} = \frac{-C_m}{C_{\text{int}}}(V_{\text{drive}} - V_{\text{ref}}) \]

2. Frequency Response

\[ v_o = G(j\omega)v_i \]
Sequential Drive and SNR

SNR decreases as the number of channel increases.
Parallel Drive

By driving all the channels in parallel, SNR increases.

\[ S_j = (S_{j1}, \ldots, S_{jL}) = \sum_{i=1}^{M} C_{ij} V_i \]

Signal Reconstruction

\[ (S_j, V_1) = (\sum_{i=1}^{M} C_{ij} V_i, V_1) \]
\[ = \sum_{i=1}^{M} C_{ij} (V_i, V_1) \]
\[ = \sum_{i=1}^{M} C_{ij} L \delta_{il} \]
\[ = C_{ij} L \]

if \( (V_i, V_l) = \sum_{k=1}^{L} V_{ik} V_{lk} = L \delta_{il} \)
SNR Comparison: Sequential vs. Parallel

(Assumption)
Sensor’s channel resistance is 0.
Measured Results: Sequential vs Parallel

Sequential Drive

Parallel Drive

#(Drive & Sense Cycle) = 348 = 87 x 4

#(Drive & Sense Cycle) = 254 = 127 x 2

#(Drive Channel) = 87
Parallel drive: Hadamard

Hadamard Matrix: Mutually Orthogonal

\[
H_1 = [1], \\
H_2 = \begin{bmatrix}
1 & 1 \\
1 & -1
\end{bmatrix}, \\
H_4 = \begin{bmatrix}
1 & 1 & 1 & 1 \\
1 & -1 & 1 & -1 \\
1 & 1 & -1 & -1 \\
1 & -1 & -1 & 1
\end{bmatrix},
\]

and

\[
H_{2^k} = \begin{bmatrix}
H_{2^{k-1}} & H_{2^{k-1}} \\
H_{2^{k-1}} & -H_{2^{k-1}}
\end{bmatrix} = H_2 \otimes H_{2^{k-1}},
\]

for \(2 \leq k \in N\), where \(\otimes\) denotes the Kronecker product.


DC saturation of the AFE vs Gain
Periodicity vs Noise Immunity
Parallel drive: M-Sequence

Shifted MLS (Maximum Length Sequence)s: Pseudo Orthogonal

MLS has Pseudo Randomness
- Less DC component
  -> No DC offset issue
- Higher Gain
- Higher SNR
- Pseudo Randomness
  -> Spread spectrum
  -> Better Noise Immunity

M-Sequence \( (L = 31 = 2^6 - 1) \)

\[
(V_i, V_j) = \sum_{k=1}^{L} V_{ik} V_{jk}
\]

\[
= L \text{ if } i = k,
\]

\[
= -1 \text{ otherwise.}
\]

[Example Sequence] 000010010110011111000110110101

generated from \( x^5 + x^2 + 1 \) (primitive polynomial)
Display Noise

Touch Sensor
# of Channel: 88 × 50
Channel pitch: 5.0mm

LCD: 19.5” FHD

Air Gap: 1.5mm

k-th sense channel

CH1: 200mV/div

Horizontal: 20us/div
Noise Cancellation by Differential Sensing

CH1: 200mV/div
CH2: 200mV/div
CH1-CH2: 20mV/div
Horizontal: 20us/div
Advantage of Differential Sensing

- Common Mode Noise Cancellation
- Higher SNR thanks to Higher Gain

\[ \begin{align*}
\text{(1) } V_{\text{out}} & \propto \frac{(C + \Delta C_{jk}) \cdot V_d + C_p \cdot V_{\text{noise}}}{C_c} \\
\text{(2) } V_{\text{outp}} - V_{\text{outm}} & \propto \frac{(\Delta C_{jk+1} - \Delta C_{jk}) \cdot V_d}{C_c}
\end{align*} \]

*V_d: driving voltage, V_{\text{noise}}: noise voltage

Two Phase Rx Circuit Operation

\[ \text{sense channel}_{2i} \quad \text{sense channel}_{2i+1} \quad \text{sense channel}_{2i+2} \]

\[ \text{Inp} \quad \text{CVC}_i \quad \text{Inn} \]

\[ i = 0, \ldots, [N/2]-1. \]


CVC: Charge to Voltage Converter
Power Supply Noise

- 68kHz (Fundamental)
- 136kHz (2nd)
- 204kHz (3rd)
- 272kHz (4th)

AC Adaptor

Battery
Environmental Noise: Fluorescent Light

![Graph showing noise levels with various frequencies labeled: 48kHz (Fundamental), 96kHz (2nd), 144kHz (3rd), 192kHz (4th), 200kHz. The graph compares noise levels with the light on and off.]
Sensor Material Requirement

- RC Time constant: ITO’s time constant is too large to realize large format sensors over 30-inch
- Light Transmittance
- Visibility: Color, Moire, etc.
- Bezel Area

### Time Constant Comparison

<table>
<thead>
<tr>
<th>Metal Mesh</th>
<th>Sheet Resistance</th>
<th>Metal Width</th>
<th>Time Constant (Normalized)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper (Thickness : 7um)</td>
<td>0.003Ω/sq.</td>
<td>7um</td>
<td>1</td>
</tr>
<tr>
<td>Silver Paste (Thickness : 9um)</td>
<td>0.2Ω/sq.</td>
<td>6um</td>
<td>78</td>
</tr>
<tr>
<td>ITO on Glass</td>
<td>20Ω/sq.</td>
<td>-</td>
<td>260</td>
</tr>
<tr>
<td>ITO on Film</td>
<td>150Ω/sq.</td>
<td>-</td>
<td>1950</td>
</tr>
</tbody>
</table>

A Random Mesh Pattern
Mesh Sensor Design Example
Capacitance Changes with a Finger
Small Capacitance Change of a Deformed Tip

Conductive fabrics

Tip Deformation
Active Pen sends out electrical signal to touch sensor. The signal can be modulated with pen’s information: the button, pressure, color, ID, etc.

Touch controller calculates stylus \((x, y)\) coordinates from the received signal and demodulates pen’s information.
One Way Active Pen System

TC synchronizes to the pen
Not easy to realize Simultaneous Multiple Pens Operation.
Two Way Active Pen System

Each pen synchronizes to TC through Uplink Beacon from TC. Easy to realize Simultaneous Multiple Pens operation.

1. Uplink: for Synchronization

2. Downlink: Multiple Stylus Detection
## Comparison of Capacitive Pen Technology

<table>
<thead>
<tr>
<th></th>
<th>Passive</th>
<th>One Way Active</th>
<th>Two Way Active</th>
</tr>
</thead>
<tbody>
<tr>
<td>Button</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Hover</td>
<td>NG</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Multiple Styluses / w Different Properties</td>
<td>OK / No</td>
<td>No / No</td>
<td>OK / OK</td>
</tr>
<tr>
<td>Dead Region*</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>In-cell Panel</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

[Dead Region]
It is impossible to detect passive pen signal placed very close to a “palm”, since the passive pen signal is small and buried in the palm signal due to its fringing capacitance.
Example of Two-Way Active Pen Protocol

FIG. 3

US9977519B2
Universality / Interoperability of Active Pen

<table>
<thead>
<tr>
<th>Architecture</th>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach 1 Pen enables all the protocol</td>
<td>Free competition</td>
<td>Complex Implementation</td>
</tr>
<tr>
<td>Approach 2 Use a unified protocol</td>
<td>Conceptually Simple</td>
<td>Restricted Competition</td>
</tr>
</tbody>
</table>
An Implementation

240Hz Multiple Active/Passive Pens with 41dB/32dB SNR for 0.5mm Diameter, 85nm CMOS(1P6M)

Figure 6.6.4: Block diagram of the AFE IC.

Figure 6.6.7: Die micrograph of the AFE.
Latest Technical Challenges
In-cell Sensors for LCD
Small Bezel → Less Design Constraints
Simple Structure → Simple Manufacturing Process / Simple Supply Chain → Low cost / Less Lead Time

**Conventional**
- Mutual Sensing
- Two Layer Out-cell Sensor
- Two ICs

**Hybrid In-cell**
- Mutual Sensing
- Hybrid In-cell Sensor
- Two ICs

**In-cell**
- Self Sensing
- In-cell Sensor
- One IC: TDDI*

*T Touch and Display Driver Integration
In-cell Segmented V-com Sensor

- No Additional Layer for Touch
- Sharing between Display and Touch Processing
Self Capacitance

Interleaved Operation for In-cell Display

CONS: Less time available for Touch/Pen processing
PROS: No Display Noise in Touch/Pen period
Technical Challenges

1. Display Technology Evolution
   - In-cell LCD
   - Foldable OLED

2. Design Constraints
   - Huge Parasitic Capacitance
   - Stronger Noise Injection

3. Signal Processing
   - Total Architecture: Sensor structure, Panel Drive, Sensing, etc.
   - Digitally Enhanced Analog Performance: Dynamic Range, SNR, etc.
Appendix
和 + computer

Harmony “Wa” between computers & human beings
Wacom Co., Ltd.

Head Office
Date of Founding: July 12, 1983
Paid-in Capital: JPY 4.2 bn. (as of March 31, 2020)
President & CEO: Nobutaka Ide
Revenue: JPY 108.5 bn. (FY 03/2021)
Employees: 1,012 (incl. temporary staff) (as of March 31, 2020)
Stock Market: Tokyo Stock Exchange 1st Section (6727)
Business Line:
- Brand products (creative pen tablet, etc.)
- Technology solution (digital pen sensor system, etc.)
学び/教えを支えるワコム液タブとペンタブ
デジタル教室/ハイブリッド教室/リモート学習/教材準備
S-penを支え続ける技術とデジタル文具エコシステム
Sシリーズにペン初搭載 / ワコムデジタル文具パートナー / 最新Note PC
世界初折り畳みPCを支えるワコムペン＆タッチ技術
今後のトレンド「折り畳みディスプレイ」にペン＆タッチ実装・商用化

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