Agenda: Part 1

- Introduction [3]
- Why There Are So Many Touch Technologies [6]
- Mainstream Touch Technologies [27]
  - Analog Resistive
  - Surface Acoustic Wave (SAW)
  - Surface Capacitive
  - Traditional Infrared (IR)
- Emerging Touch Technologies Without Multi-Touch [13]
  - Acoustic Pulse Recognition (APR - Elo)
  - Dispersive Signal Technology (DST - 3M)
  - Force Sensing
- Multi-Touch [9]
Agenda: Part 2

- Emerging Touch Technologies With Multi-Touch [64]
  - Projected Capacitive
  - LCD In-Cell (Light-, Voltage- & Charge-Sensing)
  - Optical
  - Multi-Touch (Digital) Resistive
  - Waveguide Infrared (RPO)
  - Vision-Based

- Pen Digitizer Technology [4]
  - Electromagnetic Resonance (EMR)

- Comparing Touch Technologies [5]

- Conclusions [2]
About NextWindow

NextWindow

- Develops & manufactures optical touchscreens

- Currently focused on two touch-screen markets
  - Windows-7 consumer monitors and all-in-one computers
  - Large-format display applications such as interactive digital signage

- Global presence
  - New Zealand (HQ), Singapore (Ops), USA, Taiwan, Korea, Japan
  - Manufacturing in China, Thailand and Malaysia
  - 119 employees, 55 in engineering

- Brief history
  - 2000: Founded by CTO and private investors
  - 2003: First product to market (optical touch for large displays)
  - 2005: Entered USA market
  - 2006: First major volume contract signed (HP TouchSmart AiO)
  - 2008: Entered Taiwan market with ODM focus
  - 2009: Engaged with many PC OEMs & ODMs on Win-7 products
  - 2010: Acquired by SMART Technologies
Introduction

Source: Elo TouchSystems
Two Basic Categories of Touch

- **Opaque touch**
  - Dominated by the controller chip suppliers
    - Atmel, Cypress, Synaptics, etc.
    - One technology (projected capacitive)
    - Sensor is typically developed by the device OEM
  - Notebook touchpads are the highest-revenue application
    - Synaptics ~60% share; Alps ~30% share; Elan ~10% share
    - Sensors are all two-layer projected capacitive
  - *There is no further discussion of opaque touch in this tutorial*

- **Transparent touch on top of a display**
  - Dominated by the sensor manufacturers (100+ worldwide)
  - 13 technologies
# 2009 Touchscreen Market by Size and Type of Technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>2009</th>
<th>2009</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small-Med (&lt;10”)</td>
<td>Large-Area (&gt;10”)</td>
<td>TOTAL</td>
</tr>
<tr>
<td></td>
<td>Revenue</td>
<td>Units</td>
<td>Revenue</td>
</tr>
<tr>
<td>Resistive</td>
<td>$1,284M</td>
<td>366M</td>
<td>$769M</td>
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<tr>
<td>Surface acoustic wave</td>
<td>$4.7M</td>
<td>0.1M</td>
<td>$218M</td>
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<tr>
<td>Surface capacitive</td>
<td>$0.2M</td>
<td>0M</td>
<td>$193M</td>
</tr>
<tr>
<td>Infrared</td>
<td>$4.5M</td>
<td>0.1M</td>
<td>$151M</td>
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<tr>
<td><strong>Mainstream</strong></td>
<td>$1,293M</td>
<td>366M</td>
<td>$1,331M</td>
</tr>
<tr>
<td>Emerging</td>
<td>$596M</td>
<td>40M</td>
<td>$89M</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>$1,889M</td>
<td>406M</td>
<td>$1,420M</td>
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<table>
<thead>
<tr>
<th>Technology</th>
<th>Revenue</th>
<th>Units</th>
<th>Revenue</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>Small-Medium</td>
<td>57%</td>
<td>88%</td>
<td></td>
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<tr>
<td>Large-Area</td>
<td>43%</td>
<td>12%</td>
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<td></td>
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<td><strong>TOTAL</strong></td>
<td>100%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mainstream</strong></td>
<td>79%</td>
<td>91%</td>
<td></td>
<td></td>
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<tr>
<td><strong>Emerging</strong></td>
<td>21%</td>
<td>9%</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td>100%</td>
<td>100%</td>
<td></td>
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Market size estimates are based on DisplaySearch’s “2009 Touch-Panel Market Analysis Report” with adjustments.
# 2009 Touchscreen Market by Technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>2009 Revenue</th>
<th>2009 Share</th>
<th>2009 Units</th>
<th>2009 Share</th>
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<tbody>
<tr>
<td>Analog Resistive **</td>
<td>$2053M</td>
<td>62%</td>
<td>411M</td>
<td>89%</td>
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<tr>
<td>Projected Capacitive</td>
<td>$600M</td>
<td>18%</td>
<td>40M</td>
<td>8.7%</td>
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<tr>
<td>Surface Acoustic Wave (SAW) **</td>
<td>$223M</td>
<td>6.7%</td>
<td>3.4M</td>
<td>0.7%</td>
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<tr>
<td>Surface Capacitive **</td>
<td>$193M</td>
<td>5.8%</td>
<td>2.3M</td>
<td>0.5%</td>
</tr>
<tr>
<td>Traditional Infrared **</td>
<td>$155M</td>
<td>4.7%</td>
<td>1.4M</td>
<td>0.3%</td>
</tr>
<tr>
<td>Optical</td>
<td>$66M</td>
<td>2.0%</td>
<td>1.1M</td>
<td>0.2%</td>
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<tr>
<td>LCD In-Cell (all forms)</td>
<td>$5M</td>
<td>0.2%</td>
<td>0.3M</td>
<td>0.1%</td>
</tr>
<tr>
<td>Vision-Based</td>
<td>$5M</td>
<td>0.2%</td>
<td>0M</td>
<td>0%</td>
</tr>
<tr>
<td>Acoustic Pulse Recognition (APR – Elo)</td>
<td>$4M</td>
<td>0.1%</td>
<td>0.1M</td>
<td>0%</td>
</tr>
<tr>
<td>Dispersive Signal Technology (DST – 3M)</td>
<td>$4M</td>
<td>0.1%</td>
<td>0M</td>
<td>0%</td>
</tr>
<tr>
<td>Force Sensing</td>
<td>$0M</td>
<td>0%</td>
<td>0M</td>
<td>0%</td>
</tr>
<tr>
<td>Multi-Touch (Digital) Resistive</td>
<td>$0M</td>
<td>0%</td>
<td>0M</td>
<td>0%</td>
</tr>
<tr>
<td>Waveguide Infrared (RPO)</td>
<td>$0M</td>
<td>0%</td>
<td>0M</td>
<td>0%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$3,309M</td>
<td>100%</td>
<td>460M</td>
<td>100%</td>
</tr>
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</table>

- 4 mainstream touch technologies ** ........ 79%
- #2 new kid on the block (pro-cap) ........ 18%
- Remaining emerging technologies .......... 3%

Market size estimates are based on DisplaySearch’s “2009 Touch-Panel Market Analysis Report” with adjustments.
Why There Are So Many Touch Technologies

Source: Elo TouchSystems
Why There Are So Many Touch Technologies

1. Proliferation of touch
2. Touch is an indirect measurement
3. There is no perfect touch technology
4. The drive for fundamental intellectual property
5. Vertical integration

Source: Gizmodo
Proliferation of Touch

- Self-service eliminates humans & saves $$$
- Increasing display ubiquity & decreasing display cost
- Simplification of the user interface
- Hand-eye coordination
- Shrinking device size
- Global hardware simplification
- Increased awareness of value
- Viral behavior (the iPhone effect)

Source: Apple
# Touch Is An Indirect Measurement

<table>
<thead>
<tr>
<th>What’s Being Measured</th>
<th>Touch Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>Resistive (all forms), LCD in-cell (voltage)</td>
</tr>
<tr>
<td>Current</td>
<td>Surface capacitive</td>
</tr>
<tr>
<td>Time delay</td>
<td>Surface acoustic wave</td>
</tr>
<tr>
<td>Change in capacitance</td>
<td>Projected capacitive, LCD in-cell (charge)</td>
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<tr>
<td>Absence of light</td>
<td>Optical, Infrared (all forms), LCD in-cell (light) in high ambient</td>
</tr>
<tr>
<td>Presence of light</td>
<td>LCD in-cell (light) in low ambient</td>
</tr>
<tr>
<td>Image</td>
<td>Vision-based</td>
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<tr>
<td>Bending waves</td>
<td>Acoustic Pulse Recognition (APR), Dispersive Signal Technology (DST)</td>
</tr>
<tr>
<td>Force</td>
<td>Force sensing</td>
</tr>
</tbody>
</table>

The ideal method of detecting touch has yet to be invented!
There Is No Perfect Touch Technology

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Analog Resistive</th>
<th>Projected Capacitive</th>
<th>APR</th>
<th>Waveguide Infrared</th>
<th>Traditional Infrared</th>
<th>Multi-Touch Resistive</th>
<th>LCD In-Cell</th>
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<td>Stylus Independence</td>
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<td>🟥</td>
<td>$</td>
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<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Multi-Touch</td>
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<td>$</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Durability</td>
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<td>$</td>
<td>$</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>🟥</td>
</tr>
<tr>
<td>Optical Performance</td>
<td>🟥</td>
<td>✓</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>✓</td>
<td>$</td>
</tr>
<tr>
<td>Flush Surface</td>
<td>✓</td>
<td>$</td>
<td>$</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>$</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>$</td>
<td>✓</td>
<td>$</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>$</td>
</tr>
<tr>
<td>Stable Calibration</td>
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<td>$</td>
<td>$</td>
<td>$</td>
<td>$</td>
<td>✓</td>
<td>$</td>
</tr>
<tr>
<td>Narrow Borders</td>
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<td>✓</td>
<td>$</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>$</td>
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<tr>
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<td>Cost</td>
<td>$</td>
<td>🟥</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>🟥</td>
</tr>
</tbody>
</table>

Example: Selecting the touch technology for a smartphone

- **Best**: $
- **OK**: ✓
- **Worst**: 🟥
The Drive For Fundamental Intellectual Property

- The fundamental intellectual property (IP) on all four of the traditional touch technologies has expired.
  - New patents tend to be on enhancements.

- "Cross-beam" light paths increases resolution and fault-tolerance in infrared touchscreens (Elo).

- Companies trying to establish a sustainable competitive advantage create new touch technologies.

- e.g., Touchco, SiMa Systems, FlatFrog & others…
Vertical Integration

LCD in-cell touch
- When touch was insignificant, LCD manufacturers ignored it
- Now that it’s becoming more significant, LCD manufacturers want to incorporate it into their products

“There is no perfect touch technology”
Mainstream Touch Technologies

- Analog Resistive
- Surface Acoustic Wave (SAW)
- Surface Capacitive
- Traditional Infrared (IR)

*Note: SAW & IR support multi-touch*
Analog Resistive

Source: Engadget
Analog Resistive...1

Source: Elo TouchSystems

Source: Bergquist
Analog Resistive...2

- **Types**
  - 4-wire (low cost, short life) is common in mobile devices
  - 5-wire (higher cost, long life) is common in stationary devices

- **Constructions**
  - Film (PET) + glass (previous illustration) is the most common
  - Film + film (used in some cellphones) can be made flexible
  - Glass + glass is the most durable; automotive is the primary use
  - Film + film + glass, others...

- **Options**
  - Surface treatments (AG, AR, AS), rugged substrate, dual-force touch, high-transmissivity, surface armoring, many others...

(50-uM glass) Source: Schott
Analog Resistive...3

4-Wire Construction

X-Axis

Voltage gradient applied across glass

Voltage measured on coversheet

Y-Axis

Voltage gradient applied across coversheet

Bus bar

Voltage measured on glass

Equivalent circuit
Analog Resistive...4

5-Wire Construction

X-Axis

Voltage gradient applied across glass

Contact point on coversheet is a voltage probe

Linearization pattern

Y-Axis

Voltage gradient applied across glass

Contact point on coversheet is a voltage probe

Equivalent circuit
Analog Resistive...5

- **Size range**
  - 1” to ~24” (>20” is rare)

- **Controllers**
  - Many sources
  - Single chip, embedded in chipset/CPU, or “universal” controller board

- **Advantages**
  - Works with finger, stylus or any non-sharp object
  - Lowest-cost touch technology
  - Widely available (it’s a commodity)
  - Easily sealable to IP65 or NEMA-4
  - Resistant to screen contaminants
  - Low power consumption
Analog Resistive...6

- **Disadvantages**
  - Not durable (PET top surface is easily damaged)
  - Poor optical quality (10%-20% light loss)
  - No multi-touch

- **Applications**
  - Mobile devices
  - Point of sale (POS) terminals
  - Wherever cost is #1

- **Market share**

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>62%</td>
</tr>
<tr>
<td>Volume</td>
<td>89%</td>
</tr>
</tbody>
</table>
Analog Resistive…7

- Suppliers
  - Nissha, Young Fast, J-Touch, Gunze, Truly Semi, Fujitsu, EELY, Elo TouchSystems, SMK, Swenc/TPO, eTurboTouch…
  - 60+ suppliers

- Market trends
  - Analog resistive is losing share (1st time!) to projected capacitive in the mobile market
    - First significant challenge to analog resistive’s dominance
  - Analog resistive is still very important in mobile phones in Asia
    - It supports a stylus; projected capacitive doesn’t (yet!)
Surface Acoustic Wave

Source: Kodak
Surface Acoustic Wave...1

![Diagram of Surface Acoustic Wave System]

- **Glass substrate**
- **Y-axis transmitting transducer**
- **Y-axis receiving transducer**
- **X-axis receiving transducer**
- **X-axis transmitting transducer**
- **Edge of Active Area**
- **Array of reflectors (45°)**
- **Rayleigh wave**

Source: Onetouch

Source: A-Touch
Surface Acoustic Wave...2

Source: Elo TouchSystems
Surface Acoustic Wave…3

- **Variations**
  - Ruggedization, dust-proofing, surface treatments, etc.

- **Size range**
  - 6” to 52” (but some integrators won’t use it above 32”)

- **Controllers**
  - Mostly proprietary

- **Advantages**
  - Clear substrate (high optical performance)
  - Very durable
  - Can be vandal-proofed with tempered or CS glass
  - Finger, gloved hand & soft stylus activation
Surface Acoustic Wave…4

- **Disadvantages**
  - Very sensitive to any surface contamination, including water
  - Requires “soft” (sound-absorbing) touch object
  - Can be challenging to seal
  - Relatively high activation force
  - Projects slightly above touch surface (1 mm) so can’t be flush

- **Applications**
  - Kiosks
  - Gaming

- **Market share**

<table>
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</tr>
<tr>
<td>Volume</td>
<td>1%</td>
</tr>
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</table>

Source: Euro Kiosks Network
Surface Acoustic Wave...5

- **Suppliers**
  - Elo TouchSystems, General Touch, Shenzhen Top-Touch, Leading Touch, Shenzhen KeeTouch...
  - 10+ suppliers

- **Market trends**
  - Price is dropping as Taiwanese and Chinese vendors enter the market now that Elo TouchSystems’ key patent has expired
    - Elo still has >50% of this market
  - SAW’s growth is matching the market
Surface Acoustic Wave...6

Elo’s “XYU” multi-touch SAW (demoed at SID 2009; launched 12/09)

Photo by Geoff Walker
### SAW vs. Optical Technology Comparison

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>SAW</th>
<th>Optical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Touch force</td>
<td>80 grams</td>
<td>Zero</td>
</tr>
<tr>
<td>Touch object</td>
<td>Soft</td>
<td>IR-opaque</td>
</tr>
<tr>
<td>Maximum number of touches</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Sensitivity to contamination</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Profile height</td>
<td>1 mm</td>
<td>2-3 mm</td>
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<tr>
<td>Border width</td>
<td>Large</td>
<td>Medium</td>
</tr>
<tr>
<td>Mounting &amp; bezel</td>
<td>Complex</td>
<td>Medium</td>
</tr>
<tr>
<td>Power consumption</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Occlusions &amp; ghost touches</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Sales volume</td>
<td>Just starting</td>
<td>&gt; 1M</td>
</tr>
<tr>
<td>Sole-source</td>
<td>Yes (Elo)</td>
<td>No</td>
</tr>
<tr>
<td>Cost</td>
<td>Medium</td>
<td>Low</td>
</tr>
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</table>

**Note:** SAW & optical will compete in consumer desktops
Surface Acoustic Wave...8

Special Case: Fujitsu Lab’s Mobile SAW Prototype (2007)

Enabling Technology:
Thin-film piezo transducers that are only 2 microns thick. The transducers are sandwiched in an electrode structure consisting of an array of V-shaped electrodes, all around the screen.

Source: Fujitsu Labs
Surface Capacitive

Source: 3M
Surface Capacitive...1

Source: Elo TouchSystems

Source: 3M

Scratch-resistant top coat
Hard coat with AG
Electrode pattern
Conductive coating (ATO, ITO or TO)
Glass
Optional bottom shield (not shown)
Surface Capacitive...2

- **Variations**
  - Rugged substrate

- **Size range**
  - 6.4” to 32”

- **Controllers**
  - 3M, Hampshire, eGalax, Digitech and Billabs (ISI)

- **Advantages**
  - Excellent drag performance with extremely smooth surface
  - Much more durable than analog resistive
  - Resistant to contamination
  - Highly sensitive

Source: 3M

Source: Billabs
Surface Capacitive...3

- **Disadvantages**
  - Finger-only
  - Calibration drift
  - Susceptible to EMI (no mobile use)
  - Moderate optical quality (85% - 90% transmissivity)

- **Applications**
  - Regulated (casino) gaming
  - Kiosks
  - ATMs

- **Market share**

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>6%</td>
</tr>
<tr>
<td>Volume</td>
<td>1%</td>
</tr>
</tbody>
</table>

Source: 3M
Surface Capacitive...4

- **Suppliers**
  - 3M, DanoTech, Elo TouchSystems, EELY, DigiTech, eTurbo, Optera, Touch International, Higgstec…
  - 16+ suppliers (dominated by 3M)

- **Market trends**
  - Surface capacitive isn’t growing with the touch market
    - No multi-touch capability; other significant disadvantages
    - Casinos (major market) are starting to experiment with other touch technologies
  - Price is dropping as Taiwanese and Chinese suppliers enter the market now that 3M’s key patent has expired
A New Spin: Wacom’s RRFC

Surface Capacitive Technology

How it works

- AC voltage on 2 adjacent corners; DC voltage on other 2 corners
  - Creates ramp-shaped electrostatic field across surface

- Controller switches signals around all 4 corners, creating 4 ramp fields vs. single flat field in standard capacitive
  - Current flow is measured in each case

- Resulting signal representing touch event is independent of all capacitance effects except those due to finger touch

- Controller does additional digital signal processing to compensate for factors that affect accuracy and drift

RRFC = Reversing Ramped Field Capacitive

Source: Wacom

(Trademark = CapPLUS)
Wacom’s RRFC Technology…2

- **Advantages**
  - Solves all the problems of traditional surface capacitive
    - Works in mobile & stationary devices (10” to 32” now; 3” to 46” soon)
    - Unaffected by grounding changes, EMI, variations in skin dryness & finger size, temperature, humidity, metal bezels, etc.
    - Works through latex or polypropylene gloves
    - Allows 4X thicker hardcoat for improved durability
    - Screen works outdoors in rain and snow
  - Uses same ASIC as Wacom’s EMR pen digitizer, so dual-mode input is lower cost & more efficient (e.g., in Tablet PC)

- **Disadvantages**
  - No multi-touch
  - Sole-source supplier
Traditional Infrared
Traditional Infrared…1

Source: Elo TouchSystems
Traditional Infrared...2

- **Variations**
  - Bare PCA vs. enclosed frame; frame width & profile height; enhanced sunlight immunity; force-sensing

- **Size range**
  - 8” to 150”

- **Controllers**
  - Mostly proprietary, except IRTouch

- **Advantages**
  - Scaleable to very large sizes
  - Multi-touch capable (2-4 touches)
  - Can be activated with any IR-opaque object
  - High durability, optical performance and sealability
  - Doesn’t require a substrate
Disadvantages
- Profile height (IR transceivers project above touch surface)
- Bezel must be designed to include IR-transparent window
- Sunlight immunity can be a problem in extreme environments
- Surface obstruction or hover can cause a false touch
- Low resolution
- High cost

Applications
- POS
- Kiosks
- Large displays (digital signage)

Market share

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>5%</td>
</tr>
<tr>
<td>Volume</td>
<td>&lt;1%</td>
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</tbody>
</table>
Traditional Infrared...4

- **Selected suppliers**
  - Elo TouchSystems, IRTouch, Minato, Nexio...
  - 10+ suppliers

- **Market trends**
  - Interest in IR is re-awakening as Asian vendors bring down prices, large displays become more common, and digital signage becomes more affordable
  - IR is growing, but isn’t keeping up with the market

50” plasma display with infrared touch-screen from Netrax
Elo’s “XYU” multi-touch traditional infrared (two-touch version first shown in 2008; launch expected in 2010)
Special Case: Neonode cellphone implemented with traditional infrared touch

- Same battery life as iPhone
- Low profile height (~1.7mm)
- Finger-only
- No multi-touch

Neonode couldn’t complete in the cellphone market and went bankrupt in 2009

Source: Neonode & Pen Computing
Emerging Touch Technologies

*Without* Multi-Touch

- Acoustic Pulse Recognition (APR - Elo)
- Dispersive Signal Technology (DST – 3M)
- Force Sensing (Vissumo)
Acoustic Pulse Recognition (APR)

“Zero-Bezel” Single piece of glass (no bezel); black margin is fired-on glass frit on underside

Source: Elo TouchSystems
Acoustic Pulse Recognition (APR)…1

- Plain glass sensor with 4 piezos on the edges
- Table look-up of bending wave samples ("acoustic touch signatures")

Source: Elo TouchSystems
Acoustic Pulse Recognition (APR)…2

- **Variations**
  - “Stationary APR” from 10” to 52” with controller board
  - “Mobile APR” from 2.8” to 10” with controller ASIC

- **Size range**
  2.8” to 52”

- **Controllers**
  - Proprietary

- **Advantages**
  - Works with finger, stylus or any other touch object
  - Very durable & transparent touch sensor
  - Resistant to surface contamination; works with scratches
  - Totally flush top surface (“Zero-Bezel”)
  - Very simple sensor (plain glass + 4 piezoelectric transducers)
Acoustic Pulse Recognition (APR)…3

- **Disadvantages**
  - No “touch & hold”; no multi-touch
    (both are under development & should appear in 2010)
  - Requires enough touch-force (tap) to generate sound
  - Control of mounting method in bezel is critical

- **Applications**
  - POS, kiosks, gaming, mobile devices

- **Market share**
  - <1% (first production in Elo monitors was at the end of 2006)

- **Supplier**
  - Elo TouchSystems (sole source)

- **Market trends**
  - Elo has begun shipping APR to mobile device OEMs
Acoustic Pulse Recognition (APR)...4

Elo’s “Zero-Bezel” APR with capacitive buttons & scroll-wheel in lower-right corner (SID 2009)
Breaking News!

- Elo (Tyco Electronics) purchased Sensitive Object (www.sensitive-object.com) on 1/27/10 for $62M (wow!)
- Sensitive Object’s technology is so similar to APR that the two companies cross-licensed in July, 2007

Source: Sensitive Object
Dispersive Signal Technology (DST)

Source: 3M
Dispersive Signal Technology…1

- Plain glass sensor with 4 piezos in the corners
- Real-time analysis of bending waves in the glass (“time of flight” calculation)

Source: 3M
Dispersive Signal Technology…2

- Variations
  - None

- Size range
  - 32” to 46” (3M is likely to expand into larger sizes)

- Controller
  - Proprietary

- Advantages
  - Very simple sensor (plain glass + 4 piezoelectric transducers)
  - Works with finger, stylus or any other touch object
  - Very durable & transparent touch sensor
  - Operates with static objects or scratches on the touch surface
  - Fast response; highly repeatable touch accuracy; light touch
Dispersive Signal Technology...3

- **Disadvantages**
  - No “touch & hold”; no multi-touch
  - Control of mounting method in bezel is critical

- **Applications**
  - Interactive digital signage; point-of-information (POI)

- **Market share**
  - < 1%

- **Supplier**
  - 3M (sole source)

- **Market trends**
  - DST still has a relatively low market profile due to 3M’s very conservative rollout
  - 3M avoids cannibalizing their surface-capacitive sales (<32”)
# APR vs. DST
## Technology Comparison

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>APR</th>
<th>DST</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size range</td>
<td>2.8”-52”</td>
<td>32”-46”</td>
<td>3M surface capacitive is 5.7”-32”</td>
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<tr>
<td>Methodology</td>
<td>Table lookup</td>
<td>Real-time</td>
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<td>Measurement</td>
<td>Bending waves</td>
<td>Bending waves</td>
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<td>Multi-touch</td>
<td>Under development</td>
<td>Gestures announced</td>
<td>3M’s “multi-touch gestures” only work with two moving points</td>
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<tr>
<td>Touch &amp; hold</td>
<td>Under development</td>
<td>No</td>
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<tr>
<td>Activation force</td>
<td>Moderate</td>
<td>Light</td>
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<td>Controller</td>
<td>Chip (mobile)</td>
<td>Board (fixed)</td>
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<td></td>
<td>Board (fixed)</td>
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<tr>
<td>Mounting</td>
<td>Critical</td>
<td>Critical</td>
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<tr>
<td>Availability</td>
<td>In monitors;</td>
<td>In monitors</td>
<td>Neither technology has reached the “drop-in touch-screen” component state yet</td>
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<td></td>
<td>components for mobile devices</td>
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<tr>
<td>Others</td>
<td>Similar</td>
<td>Similar</td>
<td>Performance, materials, surface treatment, interface, etc.</td>
</tr>
</tbody>
</table>
Force Sensing
Force Sensing...1

- **Principle**
  - Suspend the touch-screen from force-sensors (strain gauges or piezos) such that movement is constrained to only the z-axis

- **Variations**
  - IBM “TouchSelect”: Strain gauges (early 1990s, unsuccessful)
  - Vissumo: “Beam-mounted” sensors (ran out of money in 2009)
  - F-Origin: “Monofilament-mounted” sensors (nothing left except IP)

- **Size range**
  - 5”-48”
Force Sensing...2

- **Advantages**
  - Complete substrate design freedom – no other touch technology can handle three-dimensional substrates with embedded moving objects

- **Disadvantages**
  - No vibration under 10 Hz; no rapid-fire touches (>200 ms required between touches); no multi-touch

- **Applications**
  - 3D architectural applications

- **Market share**
  - Zero

Source: Vissumo
Market trends

- Vissumo’s “architectural” focus (e.g., a 3D elevator control panel made of steel, glass & stone containing an embedded LCD with “soft keys” and a speaker) was strongly differentiated with some unique capabilities
Vissumo’s Amazing Demo Box

- Glass-covered LCD integrated into touch panel with “soft keys” printed on back of glass
- Raised, marble touch surface with toggle switches penetrating touch panel
- Multi-page “book” with touchable & movable metal pages
- Motor attached to and penetrating touch panel with printed speed control keys and push-pull control lever
- “Snap-dome” keys attached to touch panel; removable padded and textured keys; speaker attached with holes through the touch panel.
- Irregularly shaped, raised, textured, wooden touch surface
- 4 strain gauges supporting one touch panel
Multi-Touch

Sources: Engadget, Do Device and Good Times & Happy Days
Multi-Touch

- **Multi-touch** is defined as the ability to recognize two or more simultaneous touch points

- Multi-touch was invented in 1982 at the University of Toronto (*not by Apple in 2007!*)

- “Pinching” gestures were first defined in 1983 (*not by Apple in 2007!*)

- Windows 7 (released 10/22/09) supports multi-touch throughout the OS

- Windows 7 is structured to support an unlimited number (100?) of simultaneous touch points
Multi-Touch Architecture

- **Touchscreen Sensor**: Capable of sensing multiple simultaneous points
- **Touchscreen Controller & Driver**: Capable of delivering sets of simultaneous points to the OS
- **Operating System**: Capable of forwarding multiple streams of moving points (and acting on a defined subset of them)
- **Application**: Capable of decoding multiple streams of moving points and taking actions in response
## Multi-Touch Technologies

<table>
<thead>
<tr>
<th>Touch Technology</th>
<th>Multi-Touch Capable? (#)</th>
<th>Win-7 Logo Capable?</th>
<th>Commercial MT Product Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Capacitive</td>
<td>Yes (unlimited*)</td>
<td>Yes</td>
<td>Apple iPhone; Dell Latitude XT</td>
</tr>
<tr>
<td>Digital Resistive</td>
<td>Yes (unlimited*)</td>
<td>Yes</td>
<td>JazzMutant Music Controller</td>
</tr>
<tr>
<td>LCD In-Cell (all forms)</td>
<td>Yes (unlimited*)</td>
<td>Yes</td>
<td>Sharp Netbook</td>
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<tr>
<td>Vision-Based</td>
<td>Yes (unlimited*)</td>
<td>Yes</td>
<td>Microsoft Surface</td>
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<tr>
<td>Optical</td>
<td>Yes (4)</td>
<td>Yes</td>
<td>HP TouchSmart</td>
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<tr>
<td>Traditional Infrared (“XYU” IR from Elo)</td>
<td>Yes (4)</td>
<td>Yes</td>
<td>Products in development (2010)</td>
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<tr>
<td>Surface Acoustic Wave (“XYU” SAW from Elo)</td>
<td>Yes (2)</td>
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<td>Products in development (2010)</td>
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<tr>
<td>Waveguide Infrared (RPO)</td>
<td>Yes (2)</td>
<td>Yes</td>
<td>Products in development (2010)</td>
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<td>Bending Wave (DST – 3M)</td>
<td>Future (2)</td>
<td>Maybe</td>
<td>Technology in development (2010?)</td>
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<td>Analog Resistive</td>
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<td>No</td>
<td>--</td>
</tr>
<tr>
<td>Surface Capacitive</td>
<td>No</td>
<td>No</td>
<td>--</td>
</tr>
<tr>
<td>Force Sensing</td>
<td>No</td>
<td>No</td>
<td>--</td>
</tr>
</tbody>
</table>

* Controller-dependent, not sensor-dependent
A set of touch performance standards designed to ensure a high-quality user experience

- Test 1: Sampling Rate
- Test 2: Single-Touch Taps in 4 Corners
- Test 2: Single-Touch Taps in 5 Other Locations
- Test 4: Double Taps
- Test 5: Multi-Touch Points
- Test 6: Press and Tap
- Test 7: Straight-Line Accuracy
- Test 8: Maximum Touch Lines
- Test 9: Multi-Touch Straight Lines
- Test 10: Line Accuracy Velocity
- Test 11: Single-Touch Arcs
- Test 12: Pivot
- Test 13: Multi-Touch Arcs
- Test 14: Ghost Point Test
What’s So Hard About Multi-Touch with *Analog-Type* Sensors?

Keeping the right X with the right Y when going through occlusion

Source: Elo TouchSystems
What’s So Hard About Multi-Touch with *Digital-Type* Sensors?

Designing a controller that can put out enough points fast enough

Source: Techdu.de
How Many Touches Are Enough?

Why multi-touch will probably expand beyond two touches

1. Most research on multi-touch is being done with vision-based hardware because it’s easy to develop the hardware yourself
   - Vision-based touch supports an unlimited number of touches
   - All other multi-touch-capable technologies are difficult to build & buy

2. Projected capacitive (currently the #2 touch technology!) also supports an unlimited number of touches

3. Number of touches is one way for a touch technology vendor to differentiate themselves

4. ISVs are creative; they’ll find ways to use more touches (“If you build it, they will come”)
An Anomaly: Multi-Touch Gestures on Non-Multi-Touch Screens

- **Elo TouchSystems: “Resistive Gestures”**
  - Capable of sensing two-finger gestures on standard analog resistive touch-screens
  - Fingers must be moving to sense two points; two static touches don’t work

- **3M: “Multi-Touch Gestures on DST”**
  - Same capability & restriction as above on Dispersive Signal Technology (DST) touch-screens

- **It’s not true multi-touch, but is it good enough?**
  - Gestures are HOT, so device manufacturers want them
  - Today, multi-touch is mostly used to enable two-finger gestures
  - For mobile devices, pro-cap is ~3X the cost of analog resistive, so enabling gestures on analog resistive is attractive

Source: Elo TouchSystems
“Multi-Touch Systems that I Have Known and Loved”

www.billbuxton.com/multitouchOverview.html

“If you can only manipulate one point … you are restricted to the gestural vocabulary of a fruit fly. We were given multiple limbs for a reason. It is nice to be able to take advantage of them.”

Bill Buxton, 2008
Principal Researcher, Microsoft Research
Emerging Touch Technologies

*With* Multi-Touch

- Projected Capacitive
- LCD In-Cell
- Optical
- Digital Resistive
- Waveguide Infrared (RPO)
- Vision-Based Optical
Projected Capacitive

Source: Apple
“Perimeter scan” or “non-imaging” type (NB touchpad)

- X-axis and then Y-axis electrodes are scanned sequentially, looking for point of maximum capacitance to ground.
- Ghost points are a problem with 2 touches.
Projected Capacitive…2

“Imaging” or “all points addressable” type (Apple iPhone)

Output is an array of capacitance values for each X-Y intersection
Projected Capacitive…3

Raw data including noise

Filtered data

Gradient data

Touch region coordinates
and gradient data

"10 fingers, 2 palms and 3 others"

Source: Apple Patent Application #2006/0097991
Projected Capacitive...4

Why “Projected”? 

- A finger “steals charge” from the X-electrode, changing the capacitance between the electrodes
- E-field lines are “projected” beyond the touch surface when a finger is present
Technology variations

- Single-layer sensor (no crossovers)
  - “Self capacitance” (Apple’s term)
  - Rarely used with displays due to low resolution

- Two-layer sensor (X-Y grid)
  - “Peripheral scan” or “non-imaging” (Synaptics ClearPad™)
  - Not commonly used with displays due to limited number of touches

- Two-layer sensor (X-Y grid)
  - “All points addressable” or “imaging” or “mutual capacitance” (Apple’s term)
  - Most common configuration
  - Supports unlimited number of touches (controller-dependent)
Projected Capacitive…6

- **Sensor variations**
  - Wires between two sheets of glass (Zytronic)
  - Wires between one piece of PET and one piece of glass (Zytronic)
  - Wires between two sheets of PET (Visual Planet)
  - ITO on two pieces of glass
  - ITO on both sides of one sheet of glass
  - ITO on two pieces of PET (Touch International)
  - ITO on one piece of PET and one piece of glass
  - ITO in two layers on one piece of glass with dielectric (TPK)

- **Wires vs. ITO**
  - Wires: Visible, acceptable for intermittent use
  - ITO: Invisible, needed for continuous use
Projected Capacitive...7

- **Size range**
  - 2” to 100”+
    - ITO up to 22”; wires up to 100”+

- **Advantages**
  - Very durable (protected sensor)
  - High optical quality (ITO)
  - Unlimited multi-touch
  - Unaffected by debris or contamination
  - Enables “zero-bezel” industrial design
  - Works with curved substrates (on PET)

- **Disadvantages**
  - Finger or tethered pen only
  - High cost (dropping as usage increases)
  - Difficult to integrate due to noise sensitivity

LG-Prada mobile phone with Synaptics’ projected-capacitive touch-screen; launched 3 months before iPhone
Projected Capacitive...8

- **Applications**
  - **Consumer devices**
    - Smartphones
    - Netbooks, notebooks, Tablet PCs
    - Apple AiOs (2010)
    - Almost any consumer device < 10”
  - **Vertical-market devices**
    - Signature-capture & other POS terminals
    - “Through-glass” interactive retail signage

- **Market share**

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>18%</td>
</tr>
<tr>
<td>Volume</td>
<td>9%</td>
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</table>

Source: Mildex

Source: Verifone

Demy Digital Recipe Reader (CES 2010)
Gunze’s “Direct Printing Technology” (DPT) for large-area capacitive touchscreens (shown at SID 2009)

- Flexible pro-cap sensor
- Printed silver conductors, 0.5 ohm/sq.
- Roll-to-roll, maximum size 50”
- < 1 mm resolution
- 78% transmissivity with 20μ/300μ line/space

Source: Gunze
Projected Capacitive...10

3M 22”
10-touch pro-cap touchscreen monitor
(CES 2010)
# Projected Capacitive Suppliers!

<table>
<thead>
<tr>
<th>Pro-Cap Vendor</th>
<th>Country</th>
<th>Controller</th>
<th>Sensor</th>
<th>Pro-Cap Vendor</th>
<th>Country</th>
<th>Controller</th>
<th>Sensor</th>
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<tr>
<td>Altera</td>
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<td>No</td>
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<td>Analog Devices</td>
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<td>No</td>
<td>iTouch Electro-Optical</td>
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<td>Atmel (Quantum)/ST Micro</td>
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<td>EETI (eGalax)</td>
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<td>QuickTouch Technology</td>
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<td>Focal Tech Systems</td>
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</table>

Controller Only = 13
Sensor Only = 17
Controller & Sensor = 6
(“module”)
Projected Capacitive…12

- **Market trends**
  - Extremely strong worldwide interest
  - Rapidly increasing number of suppliers (>250% in last year)
  - Rapidly dropping prices (>50% in last 18 months)
  - Upper size limit expanding from 8” to 22”
  - OEMs’ desire for multi-touch is a key driving force, along with durability and high optical performance
  - The first significant challenge to analog resistive in mobile devices

Source: Apple

The iPod Touch
“3D” Projected capacitive: Proximity detection

- Mitsubishi 5.7” prototype
  - Hover (mouseover) function
  - Finger speed can be measured by rate of change in capacitance
  - Proximity state: Priority to sensitivity, not resolution; slow response
  - Contact state: Priority to resolution, not sensitivity; fast response

Source: TechOn
Special Case: Several Tablet PCs with N-trig’s DuoSense™ finger-and-pen digitizer

- Projected capacitive sensor with analog-to-digital chips around edge of screen to minimize noise from long analog traces

- Electrostatic digitizer using electronic pen charged by coil around periphery of sensor or powered by battery

Source: Dell
Projected Capacitive…15

N-trig’s Finger-and-Pen Digitizer Architecture

- E-field
- Transparent conductors (X-Y sensor grid)
- Excitation coil
- Controller chipset
- Serial interface to host
- Digitizer (and LCD) active area
- Frame (same mechanical outline dimensions as LCD)
- Cordless pen without battery

Source: TMD
Three Different Physical Integration Methods Used In LCD “In-Cell” Touch

<table>
<thead>
<tr>
<th>Term</th>
<th>Integration Method</th>
</tr>
</thead>
</table>
| **In-Cell** | Touch sensor is *physically inside the LCD cell*  
Touch sensor can be:  
• Light-sensing elements (light-sensing)  
• Micro-switches (voltage-sensing)  
• Capacitive electrodes (charge-sensing) |
| **On-Cell** | Touch sensor is an X-Y array of ITO conductors on the top or bottom surface of the color filter substrate  
• Capacitive-only (1) |
| **Out-Cell** | Standard touchscreen *laminated directly on top of the LCD* during manufacture  
• Key difference: An additional piece of glass is required  
• Typically only projected capacitive or analog resistive  
• New term coined by AUO – *Since this term hasn’t entered common usage yet, some LCD manufacturers still refer to this configuration as on-cell* (2) |

(1) CMO & AUO persist in labeling their on-cell capacitive (on top of the color filter glass) as “in-cell” capacitive.

(2) LGD’s 6.4-inch “on-cell capacitive” at SID 2009 was actually a laminated cover-glass with ITO patterning on the under-side (out-cell).
Three Different Technologies Used In LCD In-Cell & On-Cell Touch

- **Light-sensing** or “optical”
  - Addition of a photo-sensing element into some or all pixels
  - Works with finger, stylus, light-pen or laser pointer;
    also works as a scanner; cover glass is OK

- **Voltage-sensing** or “switch-sensing”
  - Addition of micro-switches for X & Y into some or all pixels
  - Works with finger or stylus, within damage limits of LCD
  - No cover-glass

- **Charge-sensing** or “capacitive-sensing”
  - Addition of electrodes in-cell or on-cell for capacitive sensing
  - In-cell = works with finger or stylus, within damage limits of LCD; no cover-glass
  - On-cell = works with finger-only; cover-glass is OK
## Who’s Working On What (January 2010)

<table>
<thead>
<tr>
<th>LCD Manufacturer</th>
<th>Light-Sensing</th>
<th>Voltage-Sensing</th>
<th>Charge-Sensing (in-cell or on-cell)</th>
<th>Hybrid Charge &amp; Voltage (in-cell)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUO</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Chi Mei Innolux</td>
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<tr>
<td>CPT</td>
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<tr>
<td>HannStar</td>
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<td></td>
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<tr>
<td>LG Display</td>
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<td>✓</td>
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<td>NEC</td>
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<td>Samsung</td>
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<tr>
<td>Seiko-Epson</td>
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<tr>
<td>Sharp</td>
<td>✓</td>
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<tr>
<td>Sony</td>
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<td></td>
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<tr>
<td>TMD</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

- Green = Primary
- Yellow = Secondary
- **Bold** = Most significant efforts
**Light-Sensing…1**

- **Principle**
  - Photo-sensor in each pixel or group of pixels sees shadow of finger in bright light or reflection of backlight on finger in dim light

- **Variations**
  - Number of pixels per sensing element

- **Size range**
  - 3” to 20” (LTPS or CG)
  - Unlimited (a-Si)

- **Applications**
  - Mobile devices are clearly the initial target

Source: Sharp
Light-Sensing...2

Advantages

- Integration, size, thickness, weight, ID
- Unlimited multi-touch (controller-dependent)
- Conceptually high performance
  - Low parallax error (assuming no cover glass)
  - Very accurate & linear touch-point data
  - Potentially higher resolution than LCD
- Lower manufacturing cost
- Can work as a scanner
- Capable of detecting the difference between hover & touch
  - Problematic in low ambient

All the theoretical advantages of in-cell

Sample captured image on 2.6" VGA (300 ppi)
Source: Sharp
Disadvantages

- Touching a black image doesn’t work in low ambient light
- Using a photo-sensor to reliably detect touch over the range of full sunlight to total darkness is very difficult
  - Touching object shadow vs. proximate object shadow
  - Reflection from backlight vs. reflection from external light source
- Putting a light-sensor in every pixel consumes too much of the aperture (reducing efficiency) and requires too much processing power
  - But using one light-sensing element for each X pixels (e.g., 9) reduces scanning resolution and reduces quality of digital ink
- The LCD’s display function and the touch function tend to interfere with each other (“severe EMI problems” - Sharp)
  - Speeding up the touch function makes it worse
Disadvantages (continued)

- The amount of processing power needed to operate the touch function results in high power consumption
  - Analog-to-digital conversion
  - Position determination
  - Image processing
  - Gesture/motion recognition (in OS other than Windows 7)

- A cover-glass is desirable to protect the LCD, but a cover-glass reduces touch sensitivity due to the spacing between the finger and the photo-sensing element
  - Optical bonding helps (at additional cost & lower yield)
  - Harder LCD top-polarizer is the best solution to this problem
Light-Sensing…5

- Sharp’s PC-NJ70A netbook (5/09)
  - Optical in-cell touch in 4” CG-silicon
    854x480 touchpad LCD (245 dpi)
    - 1 sensor per 9 pixels
    - LED backlight
    - Stylus & 2-finger multi-touch
    - Scanning (shape recognition)
    - Touch surface = ?
    - Japan-only; $815

- Problems
  - Need IR from backlight
  - S L O W (25% of typical touchpad speed)
  - Short battery life

First use of in-cell light-sensing touch in a commercial product

Source: Sharp
Voltage-Sensing…1

- **Principle**
  - Pressing LCD surface closes micro-switches in each pixel
  - Similar principle as emerging “digital resistive” touch technology

- **Size range**
  - 3” to 26” (AUO’s stated maximum)
  - Limited by RC-loading of (and space for) connecting traces

- **Controller**
  - Needs “isolated drive & scan”, like Stantum’s digital resistive
    - There may be significant IP restrictions in this area
  - Relative simplicity potentially allows integration into LCD driver

- **Applications**
  - No LCD manufacturer has announced any in-cell voltage-sensing LCD products yet, but mobile would be a logical target
Samsung’s design (AUO’s is very similar)
Voltage-Sensing...3

- **Advantages**
  - All the theoretical advantages of in-cell...
  - Simplest controller of the three in-cell technologies
  - Independent of ambient and back-lighting
  - One sensor per pixel would be optimum for use with a stylus, since sub-pixel resolution can be achieved by inter-pixel interpolation
Disadvantages

- Voltage-sensing won’t work with a cover glass, so the LCD can easily be damaged
  - AUO’s 2008 spec is only 100K touches at <40 grams! – although it’s unclear if it’s limited by LCD surface damage or ITO cracking
    - Typical resistive touchscreen spec is 1M touches (4-wire) or 30M touches (5-wire) at ~80 grams
  - Harder LCD top-polarizer is the best solution to this problem, but until there’s more demand for touch, it’s chicken-and-egg
- Liquid-crystal pooling can be visually distracting
  - Changing cell-spacer structure or moving to IPS are possible fixes
- Reduction in aperture causes reduces efficiency
- Finite (non-zero) activation force, which can make multi-touch gestures more difficult to perform than with capacitive
- “Unstable contact” at the edge of the screen (LGD)
Charge-Sensing...1 (In-Cell)

- **In-cell**
  - Capacitive-sensing ITO electrodes added inside the LCD cell (sometimes called “pressed capacitive”)

- **Principle**
  - Pressing the LCD changes the dielectric constant of the liquid crystal, which changes the capacitance between the electrodes
  - Requires touching the LCD surface (low durability)
  - Works with finger or stylus; human body capacitance isn’t a factor

Source: LG Display
Charge-Sensing...2 (On-Cell)

- **On-cell**
  - Projected-capacitive X-Y electrode array added on top of the color filter glass, under the top polarizer

  ![Diagram of touchscreen layers]

  - Top polarizer
  - ITO (columns)
  - Insulator
  - ITO (rows)
  - Color Filter
  - Liquid Crystal
  - TFT Glass
  - TFT Array
  - CF Glass

- **Principle**
  - Same as standard projected-capacitive
  - Works only with finger; human body capacitance changes mutual capacitance between electrodes
  - Cover-glass (0.5 mm) can be added on top of polarizer to protect LCD surface

Source: Author
Charge-Sensing...3 (In-Cell & On-Cell)

- **Size range**
  - 3” to 24” (limited by RC-loading of traces and by space required)

- **Applications**
  - Handheld mobile devices are the initial target, followed by netbooks and notebooks

- **Advantages**
  - All the theoretical advantages of in-cell...
  - Sensing touch by measuring capacitance is well understood
  - Independent of ambient and back-lighting
  - Cover-glass can be added to protect the LCD surface (on-cell)
  - CF fabs can be modified to support manufacturing (on-cell)
Charge-Sensing...4
(In-Cell & On-Cell)

- **Disadvantages**
  - All forms of capacitive sensing are subject to electrical noise; successful integration into the LCD can be very difficult, especially as the LCD size increases or with noisy LCDs
  - Significant processing power is required in the controller in order to achieve acceptable performance
    - **In-cell** controller is relatively unique due to high level of integration with LCD, and there’s no interface standard
    - **On-cell** controller can be similar to standard pro-cap controller; **on-cell** (pro-cap) algorithms are more well-developed than in-cell
  - Lower touch resolution than light-sensing or voltage-sensing
    - Less important with **on-cell** due to finger resolution
Charge-Sensing...5
(In-Cell & On-Cell)

- **Disadvantages** *(continued)*
  - Smaller aperture ratio *(in-cell)* or X-Y electrode array *(on-cell)* reduces transmissivity
  - Liquid-crystal pooling with *(in-cell)* can be visually distracting
    - Using a cover-glass with *(on-cell)* reduces it but doesn’t eliminate it
  - *(In-cell)* charge-sensing won’t work with a cover glass, so the LCD can easily be damaged
  - Lack of stylus support with *(on-cell)* limits some applications
    - Handwriting Kanji characters with a stylus on a mobile phone is very popular in Asia
Charge-Sensing... 6

LG Display 13.3” in-cell capacitive (SID 2009)

An attempt to draw a grid of straight lines using a single finger.

Lots of pooling and ink lag!

Source: Author
LGD’s 13.3” 1280x800 in-cell charge-sensing LCD (10/09)

- Largest in-cell LCD so far
  - 1 sensor per 4x4 pixels
  - 10 gf activation force
- Launched at FPD 10/09
- Win-7 Touch Logo 2/10
- Positioning
  - High optical quality
  - Sunlight readability (AR?)
  - Preserving thinness
  - Two-touch multi-touch
- Targeted at notebooks
- Production in 2H-2010
- Price-adder for touch function = ??

Source: LG Displays
Hybrid Voltage & Charge-Sensing...1
(Samsung hTSP\(^{(1)}\))

2 sets (X&Y) per pixel or group of pixels

Blue pixel

Sensor signal line switch (X,Y)

Source: Author

Source: Samsung

Hybrid Voltage & Charge-Sensing…2

- **Principle**
  - ✦ Pressing the LCD...
    1. Changes changes the dielectric constant of the liquid crystal, which changes the capacitance between the pixel electrodes
    2. Closes the column-spacer contacts, which activates the circuit that measures the change in capacitance

- **Advantages**
  - ✦ Combining voltage & charge-sensing may make the touch measurement more efficient
  - ✦ Using a reference capacitor rather than directly measuring capacitance may make the touch measurement more reliable
    - Or is this done for IP avoidance reasons??
Hybrid Voltage & Charge-Sensing...3

- **Disadvantages**
  - Combination of in-cell voltage & charge-sensing disadvantages
    - LCD surface damage (no cover glass)
    - Liquid-crystal pooling
    - Reduced aperture (7%-8% for hTSP)
    - Noise sensitivity
    - Controller horsepower
    - Non-zero touch force
    - Lower resolution
Hybrid Voltage & Charge-Sensing...4

- Samsung ST10 camera with 3-inch 480x320 (192 ppi) transflective TFT with hTSP hybrid in-cell touch (4/09)
  - One sensor per 8 pixels (60x40 sensing matrix)
  - Works with finger or stylus, but with visible pooling
  - Surface hardness = low
  - Touch-screen includes electrostatic haptic feedback
  - Camera includes MP3, PMP & text-viewer functions

First use of any in-cell touch in a commercial product

Source: Samsung
Samsung ST550 camera with 3.5-inch 800x480 (267 ppi) transflective TFT with hTSP hybrid in-cell touch (8/09)

Source: Samsung
## Technology Comparison

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Light-Sensing</th>
<th>Voltage-Sensing</th>
<th>Charge-Sensing (In-cell)</th>
<th>Hybrid Voltage &amp; Charge</th>
<th>Charge-Sensing (On-cell)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size limit</td>
<td>20”/unlimited</td>
<td>26”</td>
<td>22”-24”</td>
<td>22”-24”</td>
<td>22”-24”</td>
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<td>Touch object</td>
<td>Finger, stylus, light-pen</td>
<td>Finger, stylus</td>
<td>Finger, stylus</td>
<td>Finger, stylus</td>
<td>Finger</td>
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<td>Touch force</td>
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<td>Some</td>
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<td>Some</td>
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<td>Touch resolution</td>
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<td>High</td>
<td>Low</td>
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<tr>
<td>Cover glass</td>
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<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>Durability</td>
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<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>High with cover-glass</td>
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<td>True flush surface (“zero bezel”)</td>
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<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes with cover-glass</td>
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<td>Transmissivity loss</td>
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<td>Medium</td>
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<td>External EMI sensitivity</td>
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<td>High</td>
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<td>Internal EMI sensitivity</td>
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<td>High</td>
<td>Medium</td>
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<td>Ambient light sensitivity</td>
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<td>None</td>
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<td>Flexible substrate</td>
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<td>No</td>
<td>Yes</td>
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<tr>
<td>Controller complexity</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Red-yellow-green color ratings are relative within the in/on-cell technologies, not within all touch technologies. Some values are the author's opinion.
Fundamental Issues

- **LCD design changes**
  - Modifying the backplane or frontplane of a single LCD to add in-cell touch costs $1M-$2M or more due to masking.
  - It is unlikely that LCD manufacturers will make these modifications throughout an entire product line; it will be just in high-volume products with a high demand for touch.

- **OEM second-sourcing**
  - Each LCD-maker is defining their own in-cell touch interface which introduces a big new source of potential incompatibility.

- **Choice of touch technology**
  - Different applications require different touch technologies; it’s almost never “one size fits all” – that’s why there are 13 touch technologies!
Status: April 2010

 Technologies

- Light-sensing has the most unresolved problems
- Voltage-sensing isn’t getting any traction
- Charge-sensing is where all the action is
- On-cell charge-sensing is easier than in-cell, but it’s finger-only
- Out-cell is the easiest of all

 Products

- One unsuccessful in-cell light-sensing netbook
- Two successful hybrid in-cell voltage & charge-sensing cameras
- One in-cell & three on-cell charge-sensing LCDs
- Almost all the focus is on <10” because >10” is more difficult and there are no clearly identified high-volume touch applications

 Conclusion

- It’s still early days – LCD in-cell touch has some distance to go to reach full commercialization
This picture was drawn on a 46” LCD equipped with a NextWindow optical touch-screen by a visitor to the AETI Exhibition in London on January 24, 2006.
Source: NextWindow
Optical...1

- Controller Electronics
- Optical Sensors
- Infrared LEDs
- Emitted & Reflected IR Light
- Optical Sensor View
- Retroreflectors
- Glass Substrate

LED reflecting directly into the optical sensor

Optical Sensor Pixel Position

Light Intensity

Touch Point
Optical...2

- **Variations**
  - OEM
  - Bezel-integrateable
  - Strap-on (aftermarket)

- **Size range**
  - 15” to 120”

- **Controllers**
  - Proprietary

Source: NextWindow
Optical…3

- **Advantages**
  - Stylus independence (ADA-compliant)
  - Superior drag performance
  - Scalability to large sizes
  - Multi-touch (dependent on # of sensors)
  - Object size recognition

- **Disadvantages**
  - Profile height (~3 mm on a 19” screen)
  - The “fly on the screen” problem (susceptibility to contaminants)

- **Applications**
  - Consumer touch monitors & AiOs (market leader)
  - Interactive digital signage; education
Optical...4

- **Market share**
  - | | 2009 |
  - Revenue | 2% |
  - Volume | <1% |

- **Suppliers**
  - NextWindow, Quanta, Lumio, Xiroku, eIT (XYFer)

- **Market event**
  - NextWindow shipped more than a half-million touchscreens in 2009 to Asus, Dell, HP, Lenovo, Medion, NEC, Samsung & Sony

- **Market trends**
  - Touch on the consumer desktop is just starting
  - The market is just becoming aware of optical touch
Multi-Touch (Digital) Resistive
Multi-Touch Resistive... 1

All Points Addressable (APA) type (competes with projected capacitive)
Multi-Touch Resistive...2

Segmented type (for vertical applications)

Opaque switch panel (the original purpose of digital resistive)

Touch Sensor:
Single-Layer (shown) or Two-Layer Matrix

Multi-Touch Controller

Source: Apex
Multi-Touch Resistive...3

3.74” x 2.12”
(128 pixels/inch)

64 x 36 sensing lines
= 1.5 mm squares
= 4.8 pixels/square

Display and
digital resistive
sensor by Wintek;
controller by
Stantum
(SID 2009)
Multi-Touch Resistive...4

9” slate digital resistive touchscreen by Stantum (SID 2009)
Multi-Touch Resistive…5

- **Types**
  - Segmented, for vertical-market applications
  - All points addressable [APA], competes with pro-cap

- **Constructions**
  - PET + Glass, PET + PET, etc. (same as analog resistive)

- **Variations**
  - Traditional
    - Simple switch (Stantum, AD Semi, Wintek)
  - New concept
    - Hybrid analog-digital
      (SiMa Systems, J-Touch)

- **Options**
  - Technically same variety as analog resistive, but less demand

Source: J-Touch
Multi-Touch Resistive...6

- **Size range**
  - 3” – 17”
  - Tradeoff between number of connections and resolution

- **Controllers**
  - Single-touch – many sources
  - Multi-touch – proprietary & emerging

- **Advantages**
  - Unlimited multi-touch
  - Simple, familiar technology
  - Lower cost than pro-cap

- **Disadvantages (mostly the same as analog resistive)**
  - Poor durability (PET top surface) & poor optical performance
  - Low resolution (except new hybrid analog-digital)
  - More expensive than analog resistive
Multi-Touch Resistive...7

- **Applications**
  - Fixed touch-location devices (e.g., button panels)
  - Multi-touch music controllers (JazzMutant/Stantum**)
  - Mobile devices

- **Market share**
  - Just starting

- **Suppliers**
  - Many suppliers for single-touch, but no standouts
  - Stantum (leader), SiMa Systems, AD Semi, J-Touch, Wintek

- **Market trends**
  - Suppliers are gearing up to compete against pro-cap

**See US patent application 2007-0198926**

Source: Jazz Mutant
Multi-Touch Resistive...8 (Actual Product)

21.5” multi-touch resistive by eTurboTouch

28 x 17 lines = 17 mm x 16 mm squares

90 pins

23” = 35 x 22 lines = 15 mm x 13 mm (114 pins)
Waveguide Infrared...1

Principle

Light Source

Transmit Side Waveguides

LCD Display

Free Space IR Grid for Shadow Detection

Receive Side Waveguides

Source: RPO

Traditional Infrared

Source: RPO
Waveguide Infrared...2

RPO’s actual construction (3.5” screen)

- IR LED
- Substrate
- Parabolic reflector
- Light path (white)
- Waveguides
- Light path (uses TIR in substrate)
- Line-scan optical sensor

Photo source: RPO; Annotation by author
Waveguide Infrared...3

- **Variations**
  - None yet

- **Size range**
  - 3” to 14”

- **Controller**
  - Proprietary

- **Advantages**
  - Much lower cost than traditional IR
  - Very low profile height (0.7 mm)
  - Higher resolution (depending on waveguide channel width)
  - Much less pre-touch (IR is only 200μ above substrate)
  - Works with a finger, stylus or any other touch object
  - Object size recognition
  - Limited multi-touch

Source: RPO
Waveguide Infrared...4

- **Disadvantages**
  - Can’t be scaled easily to large sizes (border width)
  - Power consumption (positioned as = to light loss of resistive)
  - The “fly on the screen” problem (IR is only 200µ above substrate)

- **Applications**
  - Mobile devices & automotive (maybe)

- **Market share**
  - Not in a shipping device yet as of 01/10, although RPO says they now have a committed OEM

- **Suppliers**
  - RPO (Australian startup; sole source)
Waveguide Infrared...5

- **Market events**
  - RPO...
    - Announced IR optical-waveguide touch at SID 2007
    - Showed improved performance at SID 2008
    - Showed larger sizes at SID 2009
    - Hooked their first OEM in late summer 2009

- **Market trends**
  - RPO may benefit from the general increase in interest in infrared, as well as from the growing interest in alternative touch technologies for mobile
Vision-Based

Source: Perceptive Pixel
Vision-Based...1

Principle (simplest version)

Multiple touch points; Image taken without a diffuser (Source: Perceptive Pixel)

Frustrated Total Internal Reflection (FTIR)

Source: Perceptive Pixel
Microsoft Surface

“Surface computing is about integrating the physical and virtual worlds through the use of vision-based touch”

Source: Information Display

Projector resolution
1024x768

-------------

Touch resolution
1280x960

1 – Screen with diffuser
2 – IR LED light source
3 – Four IR cameras
4 – DLP projector
5 – Vista desktop

Source: Popular Mechanics
Vision-Based...3

- **Variations**
  - IR injected into the cover glass; touch points seen via FTIR
  - IR illuminates underside of cover glass; touch points reflect IR

- **Size range**
  - As described, 30” and up

- **Substrates**
  - Glass or acrylic

- **Advantages**
  - Combination touch-screen and rear-projection screen
  - Alternative to IR and projected-capacitive for rear projection
  - Unlimited multi-touch (MS Surface spec is 52 touches max)
Disadvantages
- As described, for use with rear-projection only
- Finger-only (FTIR) or IR-reflecting object (Surface)

Applications
- Interactive “video walls”; digital signage; high-end retail

Market share
- << 1%

Suppliers
- Microsoft (Surface)
- Perceptive Pixel (Jeff Han’s famous videos)
- GestureTek
- “”Build Your Own Multi-Touch Surface Computer” – Maximum PC magazine (4/09)
Vision-Based... 5

- **Market event**
  - The emergence of Microsoft’s Surface product as an actual, for-sale, shipping product rather than just a research platform

- **Market trends**
  - Because a vision-based touch system can be assembled very easily, it’s the most common platform used for research
  - Research therefore tends to explore applications that make use of **many** touch points, which may bias the market towards the four (out of 13) technologies that provide “unlimited” touches
    - Projected Capacitive
    - Digital Resistive
    - Vision-Based
    - LCD In-Cell
Pen Digitizer Technology

Electromagnetic Resonance (EMR)

Source: Wacom
EMR Pen Digitizer...1

Cordless pen without battery

Pen equivalent circuit

Pressure-sensitive capacitor ($C_{\text{Tip}}$)
Coil (L)

Sensor grid schematic

Source: Wacom

Pressure-sensitive capacitor ($C_{\text{Tip}}$)
Coil (L)

Sensor grid schematic

Source: Wacom

Source: Wacom

(10µ copper)
EMR Pen Digitizer…2

- **Variations**
  - Sensor substrate (rigid FR4 vs. flexible 0.3 - 0.6 mm PET)
  - Pen diameter (3.5 mm “PDA pen” to 14 mm “executive” pen)

- **Size range**
  - 2” to 14”

- **Controllers**
  - Proprietary

- **Advantages**
  - Very high resolution (1,000 dpi)
  - Pen “hover” (mouseover = move cursor without clicking)
  - Sensor is behind LCD = high durability & no optical degradation
  - Batteryless, pressure-sensitive pen

![Diagram of EMR Pen Digitizer components](image)

Source: Wacom

Single controller can run both pen digitizer & pro-cap finger touch
EMR Pen Digitizer…3

- **Disadvantages**
  - Electronic pen = disables product if lost; relatively expensive
  - Difficult integration requires lots of shielding in mobile computer
  - Sensor can’t be integrated with some LCDs
  - Single-source = relatively high cost

- **Applications**
  - Tablet PCs
  - Opaque desktop graphics tablets
  - Integrated tablet (pen) monitors
  - E-book readers
  - Smartphones… but zero traction

- **Market share**
  - 100% share in Tablet PCs
    - Failed challengers: FinePoint/InPlay, Aiptek, Acecad, KYE, Synaptics, UC-Logic, Wintime
  - Majority share in graphics tablets & tablet monitors

Wacom “Bamboo” Tablet
EMR Pen Digitizer...4

- **Suppliers**
  - Wacom, Hanvon, Walttop, UC-Logic/Sunrex

- **Market trends**
  - Microsoft significantly de-emphasized the pen in Windows 7, so Wacom is selling into Tablet PCs against a headwind
  - Pen in general is undergoing a lessening of importance
    - iPhone and many imitators
    - Tablet PCs still a niche
    - iPad... doesn’t have a pen!
  - E-book readers are a natural fit IF annotation is important…

E-Ink 9.7” Prototype EMR Kit
Comparing Touch Technologies
## Touch Technology vs. Screen Size

<table>
<thead>
<tr>
<th>Touch Technology</th>
<th>Small 2&quot; – 10&quot;</th>
<th>Medium 10&quot; – 30&quot;</th>
<th>Large 30&quot; – 150&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Resistive</td>
<td>High</td>
<td>Medium</td>
<td>X</td>
</tr>
<tr>
<td>Digital Resistive</td>
<td>High</td>
<td>Low</td>
<td>X</td>
</tr>
<tr>
<td>Surface Capacitive</td>
<td>Low</td>
<td>High</td>
<td>X</td>
</tr>
<tr>
<td>Surface Acoustic Wave</td>
<td>X</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Traditional Infrared</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Projected Capacitive</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Optical</td>
<td>X</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>APR</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>DST</td>
<td>X</td>
<td>X</td>
<td>High</td>
</tr>
<tr>
<td>Force Sensing</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Waveguide Infrared</td>
<td>High</td>
<td>Low</td>
<td>X</td>
</tr>
<tr>
<td>Vision-Based Optical</td>
<td>X</td>
<td>X</td>
<td>High</td>
</tr>
<tr>
<td>LCD In-Cell (Light)</td>
<td>Medium</td>
<td>Low</td>
<td>X</td>
</tr>
<tr>
<td>LCD In-Cell (Voltage)</td>
<td>Medium</td>
<td>Low</td>
<td>X</td>
</tr>
<tr>
<td>LCD In-Cell (Charge)</td>
<td>Medium</td>
<td>Low</td>
<td>X</td>
</tr>
<tr>
<td>LCD On-Cell (Charge)</td>
<td>High</td>
<td>Medium</td>
<td>X</td>
</tr>
</tbody>
</table>

---

*Market penetration and/or applicability*

- High
- Medium
- Low
- X (None)
# Touch Technology vs. Application

<table>
<thead>
<tr>
<th>Application</th>
<th>Example</th>
<th>Touch Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kiosk Point of Info (POI)</td>
<td>Museum information</td>
<td></td>
</tr>
<tr>
<td>Kiosk Commerce</td>
<td>Digital photo printing</td>
<td></td>
</tr>
<tr>
<td>Kiosk Ruggedized</td>
<td>Gas pump</td>
<td></td>
</tr>
<tr>
<td>Point of Sale (POS)</td>
<td>Restaurant; lottery</td>
<td></td>
</tr>
<tr>
<td>Office Automation</td>
<td>Office monitor</td>
<td></td>
</tr>
<tr>
<td>Industrial Control</td>
<td>Machine control</td>
<td></td>
</tr>
<tr>
<td>Medical Equipment</td>
<td>Medical devices</td>
<td></td>
</tr>
<tr>
<td>Healthcare</td>
<td>Patient info monitor</td>
<td></td>
</tr>
<tr>
<td>Military Fixed &amp; Mobile</td>
<td>Submarine console</td>
<td></td>
</tr>
<tr>
<td>Training &amp; Conference</td>
<td>Boardroom display</td>
<td></td>
</tr>
<tr>
<td>Legal Gaming</td>
<td>Casino machine</td>
<td></td>
</tr>
<tr>
<td>Amusement Gaming</td>
<td>Bar-top game</td>
<td></td>
</tr>
<tr>
<td>In-Vehicle</td>
<td>GPS navigation</td>
<td></td>
</tr>
<tr>
<td>ATM Machine</td>
<td>ATM machine</td>
<td></td>
</tr>
<tr>
<td>Mobile Device</td>
<td>Smartphone</td>
<td></td>
</tr>
<tr>
<td>Appliance</td>
<td>Refrigerator door</td>
<td></td>
</tr>
<tr>
<td>Architectural</td>
<td>Elevator control</td>
<td></td>
</tr>
<tr>
<td>Consumer AiO &amp; Monitor</td>
<td>HP TouchSmart</td>
<td></td>
</tr>
<tr>
<td>Music Controller</td>
<td>Jazz Mutant</td>
<td></td>
</tr>
<tr>
<td>Digital Signage</td>
<td>Thru-window store</td>
<td></td>
</tr>
</tbody>
</table>

*Touch Technologies: Analog Resistive, Digital Resistive, Surface Capacitive, Projected Capacitive, SAW, Traditional IR, Waveguide IR, Optical, APR, DST, Force Sensing, LCD In-Cell (Light), LCD In-Cell (Voltage), LCD In-Cell (Charge), LCD On-Cell (Charge).*
# 13 Usability Characteristics

<table>
<thead>
<tr>
<th>Desirable Characteristic</th>
<th>Touch Technologies</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Analog Resistive</td>
<td>Digital Resistive</td>
</tr>
<tr>
<td>Touch with any object</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>No unintended touch</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Multi-touch</td>
<td>L</td>
<td>H</td>
</tr>
<tr>
<td>Touch &amp; hold</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>High durability</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>High sensitivity (light touch)</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Fast response &amp; drag</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Stable calibration</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>Very smooth surface</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>No liquid crystal pooling</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Resistant to contaminants</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Works in rain, snow &amp; ice</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Works with scratches</td>
<td>L</td>
<td>L</td>
</tr>
</tbody>
</table>
# 13 Performance Characteristics

<table>
<thead>
<tr>
<th>Desirable Characteristic</th>
<th>Touch Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>Analog Resistive</td>
</tr>
<tr>
<td>High optical performance</td>
<td>L</td>
</tr>
<tr>
<td>High resolution</td>
<td>H</td>
</tr>
<tr>
<td>High linearity</td>
<td>H</td>
</tr>
<tr>
<td>High accuracy &amp; repeatability</td>
<td>H</td>
</tr>
<tr>
<td>Low power consumption</td>
<td>H</td>
</tr>
<tr>
<td>Insensitive to vibration</td>
<td>H</td>
</tr>
<tr>
<td>Insensitive to EMI &amp; RFI</td>
<td>H</td>
</tr>
<tr>
<td>Insensitive to ambient light</td>
<td>H</td>
</tr>
<tr>
<td>Insensitive to UV light</td>
<td>L</td>
</tr>
<tr>
<td>Touch-object size recognition</td>
<td>L</td>
</tr>
<tr>
<td>Measures Z-axis</td>
<td>L</td>
</tr>
<tr>
<td>Handwriting recognition</td>
<td>H</td>
</tr>
<tr>
<td>Works with bi-stable reflective</td>
<td>H</td>
</tr>
</tbody>
</table>
### 13 Integration Characteristics

**Desirable Characteristic**

<table>
<thead>
<tr>
<th>Integration</th>
<th>Touch Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate independence</td>
<td>M M L H L H H H L L L L L</td>
</tr>
<tr>
<td>Scalable</td>
<td>M L M H M M L H H H H H H</td>
</tr>
<tr>
<td>Easy integration</td>
<td>H M L L M M M H L L M H H H H</td>
</tr>
<tr>
<td>Flush surface (low profile)</td>
<td>M M M H M L M L H H M H M M H H</td>
</tr>
<tr>
<td>Narrow border width</td>
<td>H M M H L L M L L L L L H H</td>
</tr>
<tr>
<td>Thin and light</td>
<td>H H L H L L M L L L L L H H</td>
</tr>
<tr>
<td>Easy to seal</td>
<td>H H H H L M M M H H M M L L M</td>
</tr>
<tr>
<td>Can be vandal-proofed</td>
<td>L L M H H M M L H H H L L L L</td>
</tr>
<tr>
<td>Works on curved surface</td>
<td>M M L H L L L L L H H L L H H</td>
</tr>
<tr>
<td>Can be laminated to LCD</td>
<td>H H H H M M H H L L L L H H</td>
</tr>
<tr>
<td>HiD (Plug &amp; Play) interface</td>
<td>L L L L L L H L H L L L L L</td>
</tr>
<tr>
<td>Simple controller</td>
<td>H M L L L M M L H H M H M M</td>
</tr>
<tr>
<td>Controller chip available</td>
<td>H H L H H L H L H L L L L L</td>
</tr>
</tbody>
</table>
Conclusions

Source: CG4TV
There Is No Perfect Touch Technology!

<table>
<thead>
<tr>
<th>Technology</th>
<th>Major Advantage</th>
<th>Major Flaw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Resistive</td>
<td>Low cost</td>
<td>Low durability</td>
</tr>
<tr>
<td>Multi-Touch (Digital) Resistive</td>
<td>Multi-touch</td>
<td>Connections</td>
</tr>
<tr>
<td>Surface Capacitive</td>
<td>Touch sensitivity</td>
<td>High drift</td>
</tr>
<tr>
<td>Projected Capacitive</td>
<td>Multi-touch</td>
<td>Finger-only</td>
</tr>
<tr>
<td>Surface Acoustic Wave</td>
<td>Durability</td>
<td>Soft touch object</td>
</tr>
<tr>
<td>Traditional Infrared</td>
<td>Reliability</td>
<td>High cost</td>
</tr>
<tr>
<td>Waveguide Infrared</td>
<td>Low cost</td>
<td>Contamination</td>
</tr>
<tr>
<td>Optical</td>
<td>Scalability</td>
<td>Profile height</td>
</tr>
<tr>
<td>Acoustic Pulse Recognition</td>
<td>Any touch-object</td>
<td>No touch &amp; hold</td>
</tr>
<tr>
<td>Dispersive Signal Technology</td>
<td>Any touch-object</td>
<td>No touch &amp; hold</td>
</tr>
<tr>
<td>Force Sensing</td>
<td>3D substrate</td>
<td>Vibration</td>
</tr>
<tr>
<td>Vision-Based</td>
<td>Multi-touch</td>
<td>Rear projection</td>
</tr>
<tr>
<td>LCD In-Cell (Light-Sensing)</td>
<td>Integration</td>
<td>Sensitivity</td>
</tr>
<tr>
<td>LCD In-Cell (Voltage-Sensing)</td>
<td>Integration</td>
<td>Durability</td>
</tr>
<tr>
<td>LCD In-Cell (Charge-Sensing)</td>
<td>Integration</td>
<td>Durability</td>
</tr>
<tr>
<td>LCD On-Cell (Charge-Sensing)</td>
<td>Integration</td>
<td>Finger-only</td>
</tr>
</tbody>
</table>
A Prediction of Which Technologies Will Win in the Next Five Years

<table>
<thead>
<tr>
<th>Application</th>
<th>Winning Technology</th>
<th>Runner-Up Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automotive</td>
<td>Analog Resistive</td>
<td>Projected Capacitive</td>
</tr>
<tr>
<td>Casino Gaming</td>
<td>Surface Capacitive</td>
<td>Projected Capacitive</td>
</tr>
<tr>
<td>Consumer AiOs and Monitors</td>
<td>Optical</td>
<td>Projected Capacitive</td>
</tr>
<tr>
<td>Consumer Notebooks</td>
<td>Projected Capacitive</td>
<td>Optical</td>
</tr>
<tr>
<td>Interactive Digital Signage</td>
<td>Optical</td>
<td>Traditional Infrared</td>
</tr>
<tr>
<td>Kiosks</td>
<td>Surface Acoustic Wave</td>
<td>Surface Capacitive</td>
</tr>
<tr>
<td>Mobile Devices</td>
<td>Projected Capacitive</td>
<td>Analog Resistive</td>
</tr>
<tr>
<td>POS Terminals</td>
<td>Analog Resistive</td>
<td>Traditional Infrared</td>
</tr>
</tbody>
</table>
Thank You!

Geoff Walker
Marketing Evangelist & Industry Guru
NextWindow
7020 Koll Center Parkway, Suite 138
Pleasanton, CA 94566
1-408-506-7556 (mobile)
gwalker@nextwindow.com