How to make innovations!

- Lessons learned by several display innovations -

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Abstract: Revolutionary innovations (also called discontinuous innovations) which are often disruptive and new is a synonym for a risk-taking. Organizations that create revolutionary products or technologies take on the greatest risk because they create new markets. We cannot predict revolutionary innovation, which also makes it very difficult to start researching such kinds of disruptive technologies. I would like to introduce some revolutionary innovative display technologies based on my experience to give you some hints to start them as the researchers which challenge common sense.

At first, I mainly focus on LCD technologies to create and open a new flat panel TV market. In 1990, it was said that the motion blur problem for LCD TVs was impossible to be solved without ultra-fast response materials. However, we discovered that the motion blur was caused not by the binary response as a common-sense would suggest at that time. Rather it is due to both - drastically degraded gray-level response (brightness in the middle between 0% black and 100% white), and the decrease in the driving voltage because of the electrostatic capacity change according to the rotation of the liquid crystal molecules. Based on the novel image-lag mechanism, we invented the overdrive method that is a liquid crystal driving method to emphasize the applied voltage to the liquid crystal only for a certain period according to the change in the pictures (brightness) so that it may compensate for the liquid crystal response deterioration. After that, it took more than 13 years to put it on the market. I also would like to tell you about why so much time was required to make the revolutionary innovation.
What is innovation?

Innovation: Break common sense

KPS is inventing the fusion of new hardware and software in different technical fields
Haruhiko Okumura received his MS and Ph.D. degrees in electrical Engineering from Waseda Univ., in 1983 and 1995, respectively. He joined Toshiba R & D Center, Kawasaki, Japan, in 1983. He has been engaged in working on developing image processing for image sensor, image compression and flat panel displays, especially LCDs.

He received the Special Recognition Award of SID in 2004, the Ichimura Industrial Award in 2007 The Imperial Invention Award in 2009.

He was a SID Japan Chapter Chair, an IEEE CE Society East Joint Chapter Chair, Vice president for LC society and IDW General Chair. IEEE CESo DL, IEEE Fellow, SID Fellow

Dr. Okumura is “Inventor of Overdrive technology”
My expertise and interests:

| Camera | Circuit | Image coding | Image processing | Image evaluation | AR/VR system |

Innovation: Overdrive LCD 3D-II TV Monocular HUD

My expertise: Human Centric Imaging techs

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Outlines

- History of past innovation technologies for displays
- Case study(1): “Overdrive technology” (Toshiba)
- Case study(2): “3D Display” (Toshiba, as a manager)
- Summary

Next lecture:

- Next innovation for display technologies in the future
- Device: Flexible display technologies/ μ—LED technology
- System: AR/VR display technologies
- Summary
The 6000 members of SID are professionals in all of the technical and business disciplines that relate to display research, design, manufacturing, applications, marketing, and sales. Each member belongs to the SID chapter of his or her choice. We invite you to join us in developing and manufacturing the displays for the 21st century, and applying them to exciting information, telecommunications, medical, commercial, government, entertainment, and consumer products.

The Society for Information Display

When you join the Society for Information Display, you are joining the international display community — and a local one. From Osaka to Eindhoven, you will find 6000 colleagues passionately involved in display and display-system design, integration, marketing, display standards, manufacturing, human factors, applications, and R&D.

Each of these 6000 display professionals is a member of the chapter of his or her choice. The chapters have periodic meetings, and some run conferences and trade shows that have national — even international — appeal. The chapters interact both directly and through the central SID International Office, and chapter meetings often feature speakers with international reputations. SID’s largest international gathering is the annual SID Symposium, Seminar, and Exposition, which attracts thousands of attendees, speakers, and exhibitors from around the world. Here, the members of the international display community come together face to face, share technical information, develop business opportunities, and make new friends — just as we have done since 1962. We invite you to join us.
Innovative techs for AM-LCD

Toshiba 2 technologies:
① Low Temperature p-Si
② Overdrive technology
(1) Case of Overdrive technology

Toshiba (Dr. Okumura):
Toshiba Innovation Products

World 1st or Japan 1st Toshiba Innovation Products

Japan 1st Toshiba Innovation Products
- Light bulb (1890)
- Washing machine (1930)
- Refrigerator (1930)
- Electric rice-cooker (1955)

Japan 1st Products
- Japanese word processor (1978)

World 1st Products
- Laptop PC (1985)

World 1st Products
- DVD Player (1996)
- LCD-TV with OD (2003)
- 3D II-TV (2011)
What is Overdrive technology (OD)?

Overdrive technology is defact standard technology for LCDs in the world.
History of the Overdrive technology at Toshiba

This is very long way to put the OD tech. into market

1. **First stage**
   - Invention & Prototyping
   - Concept proposal
   - Performance Evaluation & Optimization

2. **Second stage**
   - Development
   - Low cost
   - Memory capacity reduction

3. **Third stage**
   - Tech Transfer
   - New concept
   - Software Process
   - High speed processing

4. **Development at business unit**

5. **Exhibition**
   - HD TV
   - Low cost
   - Tech Transfer

6. **For TVs**
   - For TV&PC

7. **PR at exhibition**

8. **R&D PJ**

9. **LAO SLAO Product**
Background of Overdrive technology for Flat TV

CRT technology vs LCD technology (in 1990)

In 1990
* TV market trend: CRT golden age
  Monopolized by CRT
  Third wave of CRT/
  Large-size TV

* LCD market:
  Third generation/
  Beginning of
  high quality still image
  For note PC

Our big challenge: To compete with the CRT, we invented an overdrive technology to improve motion image quality in 1990.
Overdrive tech. invented by uncommon sense:
It had a major impact on the development of LC materials

Common sense in 1990: **OD was unnecessary method**
1. Gray-level response time was less than bi-level response
2. High speed response material can solve the image-lag problem

Common sense in 2016:
1. **Overdrive tech. is essential** for LCD TVs
2. Gray level response mainly degrades the motion image

Quality of TV

Taking care of my child in the park, I felt something wrong!
OD was invented by two new findings

**New findings (1):**
Gray level response mainly degrades the motion image quality of LCD-TV.

**New findings (2):**
Fast response materials alone can not completely solve the motion blur problem due to TFT sample-hold driving.
Main issue: Low response speed for gray levels

For gray levels, even fast response LC materials did not meet the response time specification (below 1/60 seconds)
What is Overdrive technology?

Applied driving voltage to LCD is emphasized for moving pictures.
Gray scale response time by OD

Conventional

Response time [s]

Initial Gray Level

Final Gray Level

Overdrive

Response time [s]

Initial Gray Level

Final Gray Level

> 16.7 ms (1/60 second) for all gray levels

Present LC material can be applied to TV
By using Overdrive

No fast response material development is required.
Fast response for gray levels has been achieved.

By using OD technology, gray response times for all LC materials have been improved to meet the specification (below 1/60 seconds).
History of the Overdrive technology at Toshiba

This is very long way to put the OD tech. into market

- **Invention & Prototyping**
- **Concept proposal**
- **Performance Evaluation & Optimization**
- **Low cost**
- **Memory capacity reduction**

**First stage**

**Second stage**

**Tech Transfer**

**Third stage**

**R&D PJ**

**Exhibition**

**HDTV**

**Low cost Tech. Transfer**

**Development**

**PR at exhibition**

**Software Process**

**New concept**

**High speed processing**

**For TVs**

**For TV&PC**

**For PC**
Novel Concept for low-cost OD circuit
based on image compression technologies
Relationship between OD data and pre-field data

Non-linear transformation will be useful to reduce memory size

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Low cost OD technology

Input

8 bit × RGB

Non-linear quantization

8 bit × RGB

LAO data table
32 kbit

Non-linear dequantization

Frame Memory
4 Mbit

Output

8 bit × RGB

Reduced to half-size (1/2)
Image quality for Low cost OD

Basic concept OD method

OD with 8 bit data

Low cost OD with non-linear 4 bit)
This is very long way to put the OD tech. into market
Overdrive signal processing issues for PCs

Main issues:
(1) YUV signal processing is must
(2) LUT processing is very heavy: Multiply, add, subtract
High speed SLAO Algorithm

\[ L_{\text{LAO}} - L_0 = \alpha_{\text{MSE}} (L_1 - L_0) \]

- \(\alpha_{\text{MSE}}\) : LAO coefficient
- \(L_0\) : Start level
- \(L_1\) : End level
- \(L_{\text{LAO}}\) : LAO level

For LAO coefficient,

\[
\begin{bmatrix}
R_{\text{LAO}} - R_0 \\
G_{\text{LAO}} - G_0 \\
B_{\text{LAO}} - B_0
\end{bmatrix} = \alpha_{\text{MSE}}
\begin{bmatrix}
R_1 - R_0 \\
G_1 - G_0 \\
B_1 - B_0
\end{bmatrix}
\]

**Experimental Results**

- \(y = 1.4473x\)
- \(R^2 = 0.9897\)

**SLAO Algorithm**

\[
\begin{bmatrix}
Y_{\text{LAO}} \\
U_{\text{LAO}} \\
V_{\text{LAO}}
\end{bmatrix} = \alpha_{\text{MSE}}
\begin{bmatrix}
Y_1 - Y_0 \\
U_1 - U_0 \\
V_1 - V_0
\end{bmatrix} + \begin{bmatrix}
Y_0 \\
U_0 \\
V_0
\end{bmatrix}
\]
Image quality for SLAO

<table>
<thead>
<tr>
<th>LCD mode</th>
<th>TN</th>
<th>MVA</th>
<th>IPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_{SE}$</td>
<td>1.5</td>
<td>1.45</td>
<td>1.6</td>
</tr>
</tbody>
</table>

LAO coefficients with the maximum evaluated value ($\alpha_{SE}$)

- LCD (A)
  - $\alpha_{SE} = 1.5$
  - $\alpha_{MSE} = 1.38$
- LCD (B)
  - $\alpha_{SE} = 1.45$
- LCD (C)
  - $\alpha_{SE} = 1.6$
  - $\alpha_{MSE} = 1.45$

Evaluated value
- 4-5: very good
- 3-4: good
- 2-3: fair
- 1-2: bad
- 0-1: very bad
Performance for SLAO

- Processing cost of prototype SLAO system

<table>
<thead>
<tr>
<th></th>
<th>CPU</th>
<th>Pentium® III 600 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picture size</td>
<td></td>
<td>352 x 480 pixels</td>
</tr>
<tr>
<td>Bit rate</td>
<td></td>
<td>2 Mbps</td>
</tr>
<tr>
<td>SLAO processing cost</td>
<td></td>
<td>20 % of CPU capacity</td>
</tr>
<tr>
<td>MPEG2 decoding cost</td>
<td></td>
<td>40 % of CPU capacity</td>
</tr>
<tr>
<td>Total processing cost</td>
<td></td>
<td>60 % of CPU capacity</td>
</tr>
</tbody>
</table>

SLAO impact:

“We don’t do anything for overdrive tech any more.”
Number of Papers related to OD tech.

- Invented the OD method (1990)
- First OD presentation at SID (1992)
- 13 years later for product (2003)

Little and often fills the purse
LCTV Market opened by OD

First LCTV products with overdrive technology on the market in 2003

More than 250 million products in 2016

- OLED
- RP
- PDP
- LCD (LED)
- LCD (CCFL)
- CRT

(NPD Display Search)
32-in LCTV with OD on the market in 2003
Overdrive technology: De-fact standard technology for LCTVs

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The Imperial Invention Prize:

De-fact standard technology for LCTVs
Key points for success (In my case)

(1) Innovative concept making stage: Simple idea invented by the integration of wide fields of technologies I have experienced: Breaking common sense (originality)

(2) Taking the first step with strong courage against common sense and demonstrating a prototype of your idea to key-person

; Anyone who has never made a mistake has never tried anything new. /Albert Einstein (1879-1955)

Enjoy first challenge with few fellows with strong will

(3) Development & Product stage: Continuing to research on your innovative concept without give-up for at least three years, possibly more than 10 years until putting it into the market

: Little and often fills the purse
(2) Case of 3D Display Technology

Toshiba as a manager and leader (Dr. Hirayama & Mis Fukushima):
History of Toshiba glasses-free 3D-TV

Innovative 3D concept generated by different field 3 engineers

- Only 3 engineers invented
- Concept Making
- Prototyping & Marketing
- 3D-TV product project
- First 3D-TV product development
- Second mass Production Development

2002

Newspaper announcement

2005

3D-II image generation method

2010

Toshiba group collaborative 3D project: 3D panel and 3D processing

2011

Wide FOV method 2D/3D II transform method

New application for 3D II
Concept making stage (3D-TV PJ as a manager)

(1) The most important thing is how to make the organization consisting of what kinds of members: Making research team consisting of selected engineers with wide fields of technologies and with high insight for simple idea invented by the team: Diversity team

(2) Leadership: Taking the first step with strong courage against common sense and demonstrating a prototype with your future vision based on strong originality to key-person as a leader: Future trend inventor

“The best way to predict the future is to invent it.” /Alan Curtis Kay
3D requirement and market size (2002)

3D requirement and market size (million dollar @ 2005)

- 3D Fish viewing
- 3D PC Game
- 3D Game
- 3D Museum
- 3D Medical
- 3D Arcade game
- 3D TV

3D FOV [degree]

3D Depth [cm]

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3D Depth Cues: Binocular vs Monocular

**Binocular depth cues**

- Binocular disparity
- Convergence

**Monocular depth cues**

- **Perspective cues** (Static parameters)
  - Occlusion
  - View height
  - View size
  - Texture
  - Shadow
  - Aerial perspective

- **Dynamic cues** (Motion parallax)
  - Self motion
  - Object motion
3D depth Cues for Human 3D recognition

Depth Cues

- B-disparity
- B-convergence
- BM-accomodation
- M-dyna-disparity
- M-perspective
- M-aerial perspective
- B: Binocular
- M: Monocular
- BM: Binocular & Monocular

For 3D TV or 3D interaction

For 3D space recognition or Navigation

Sensitivity

Distance [m]
3D Display technologies: Principle of autostereoscopic vision

Principle of autostereoscopic vision mechanism

Principle of 3D display mechanism with 3D glasses

Images for left eye

Images for right eye
**Autostereoscopic display without special glasses**

Depending on directions from displays, we can see the different images for right and left eyes.

Assign each 4 parallax image interleavely every 4 pixels.

From the left, only parallax image 3 and 4 are observed.

From the right, only parallax image 1 and 2 are observed.
Comparison between glasses-free 3D methods

**Multi-parallax**
Focusing on the observer’s eyes, 3D objects are reconstructed by 3D display (extending 3D concept with glasses to multi-viewing 3D without glasses)

- Unnatural discontinuous transition depending on the viewing directions
- Adequate 3D resolution

**Integral Imaging(II)**
Optical ray of the real 3D objects reconstructed by 3D display

- Natural smooth transition depending on the viewing directions
- Low 3D resolution

→ Viewing area optimization and super-resolution to solve the tradeoff issue between wide FOV and high resolution
Innovative concept invented by wide-fields engineers collaboration

Common sense in 2000’s for 3D viewing area extension:
1. Due to insufficient number of pixels, small 3D viewing area
2. To extend the 3D viewing area, more pixels needed

Thinking about how to use all pixels more effectively during commuting

Collaboration team of material, device and system engineers discussed each other and invented innovative wide FOV ideas, based on each field of technologies!
Glassless II-type 3D prototype developed by the team by using extraordinary high resolution 4K display globally for the 1st time
Checking deeply the prototype, the team felt something wrong
Novel concept: FOV Optimization technology

The farther pixel location from the center is, the more tilting angle of pixel ray to the center is.

**Conventional methods**

- Narrow FOV
- Correctly reconstructed 3D Area

**Our method**

- Wide FOV
- Ray direction optimization (sliding pixel data depending on the position, as shown in bottom right figure)

3D Display
Extending effect for Field of View (FOV):

Comparison between our method and other methods

II (Our method) (FOV=±10°)

Multi-view (4 view)

Multi-view (2 View)

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History of Toshiba glasses-free 3D-TV

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- 2005
  - Newspaper announcement
- 2010
  - Only 3 engineers
- 2011
  - Toshiba group collaborative 3D project:
    - 3D panel and 3D processing CELL
    - High speed CPU

New application for 3D II
- Wide FOV method 2D/3D II transform method
- 3D II image generation method

Toshiba group collaborative 3D project:
3D panel and 3D processing CELL
High speed CPU
REGZA
55XS5
映像に圧倒的な精細感と存在感をもたらす、4K2K高画質
Development stage (3D-TV PJ as a manager)

(3) Development & Product stage: Continuous collaborating with business department and getting big investment at best timing without give-up for at least three years, possibly more than 10 years until putting it into the market.

Based on the extraordinary high originality accumulated for more than 5 years, we got a big development investment from our president, collaborating with display panel and TV system business departments: President PJ

: Little and often fills the purse
Key points for success (3D-TV PJ as a manager)

(1) Organization: Making research team consisting of selected engineers with wide fields of technologies and with high insight for simple idea invented by the team: Diversity team.

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(3) Development & Product stage: Continuous collaborating with business department and getting big investment at best timing without give-up for at least three years, possibly more than 10 years until putting it into the market: Little and often fills the purse.
Rome wasn't built in a day

- **Overdrive Technology:**
  - In 1989, three engineers started the OD development to solve the issue of slow LC response as one of the R&D projects for hang-on-a wall flat panel TV.
  - In 2002, put it on the market for the 1st time. It took more than 10 years.

- **Glass-free 3D technology:**
  - In 2000, only one device engineer started to propose the novel 3D concept and collaborating with other two material and system engineers in 2002, innovative 3D concept was invented.
  - In 2010, glass-free II type 3DTV was put on the market for the 1st time.

Expecting the future trend for 10 years and collaborating with other fields of engineers, continuous effort and eagerness until putting it on the market are required.
Thank you for your kind attention

See you next lecture

TOSHIBA
Leading Innovation

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