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Perceptual Displays Today & Tomorrow – Evangelism, Productization and Evaluation

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Abstract

Evolution of displays in various industries such as consumer electronics, aerospace, automotive, gaming and digital signage has been a key factor to engage and satisfy consumers. In this talk, I focus on Automotive market as one of the fastest growing display markets, but most discussed matters are applicable to other display verticals. Perceptual and Immersive display user experience are attracting more manufacturers these days to build products matching the end user's expectation and needs while interacting with displays such as: perfect visibility in all conditions, personalization, less eye fatigue, seamless interaction - in one word "mimic real world" experience. Hardware and software advancements are critical but not enough to fulfil today's knowledgeable consumer demands. The User Experience has become one of the highest priorities leading companies to develop dedicated user experience or UX teams to study the need of the end user. Multi-disciplinary teams of experts are built to tackle the UX optimization challenge.

In this talk I will share our experience evangelizing the benefits of Perceptual displays, challenges of such evangelism, productization of it and most importantly measuring the performance of perceptual displays in a comparable way to traditional displays.

Four Main Challenges Automotive Display Market is Facing

In this Section, we share our view on main challenges that display manufacturers face in the automotive industry and discuss potential solutions for such challenges. All the four major challenges are results of the rapid shift in user experience and expectation growth over the last decade. As a result, our suggested solutions to the challenges are also based on perceptual, human-driven studies and analysis.

All image processing solutions introduced in this section as suggested solutions to the challenges are based on

1- physiological simulations of the challenging condition,
2- measuring the amount of compensation required to avoid the challenge and
3- applying the compensation method in a new software or hardware manner, and finally
4- evaluating the impact of the compensation using perceptual image processing metrics. Evaluating/measuring the impact of the perceptual image processing solutions are discussed later in this talk.

We will discuss four major challenges we have identified in Automotive display industry in the rest of this section. The challenges are "New Architecture", "energy efficiency", "user design and safety" and "user perception/personalization".

1- New Architecture

Most display-related industries such as mobile, laptops and automotive are looking at optimizing system architecture due to rapid feature addition, fast development cycle, user expectations, recent chip shortage and so many other reasons. Automotive cockpit architecture is going through a significant change, moving away from application/function driven to user/human-driven system architecture.

Application driven cockpit architecture is based on defining one use case per ECU (Engine Control Unit), for example one processor for driving the cluster display, one processor to drive the infotainment display and another processor to drive electronic mirrors. Near future cockpit architecture requires a central ECU to drive all displays and make sure user experience is managed centrally and similarly for all displays

Figure 1: Today's application driven cockpit vs. tomorrow's human-driven cockpit architecture

Seamless user experience is key to make central architecture happen in cars. Forvia & Irystec are introducing "Immersive Display" concept with a pilar-to-pilar architecture using a combination of displays and LED arrays/tiles seamlessly to provide a unique user experience to the driver/passenger. All displays and LED tiles are running centrally making sure their colors match and the content is designed in a way that it provides the user with most relevant information as fast as possible.

Figure 2: Forvia Immersive Display

There has been some recent work done on measuring the tolerable color perception differences between different displays such as LCD and OLED [1] or between displays and LEDs in the car interior. We have recently introduced an acceptable threshold for perceived differences between color of different surfaces to ensure seamless UX as well as a method for perceptual color

matching between different light emitting systems.
Immersive display experience with a single central system architecture introduces so many challenges and room for new technical advancement. One of the works done in this area in the last year is a perceptual color matching between different screens/light-emitting devices. Below is an example of an LCD display on the side of an LED tile shown before (first row) and after (second row) perceptual color matching processing done.

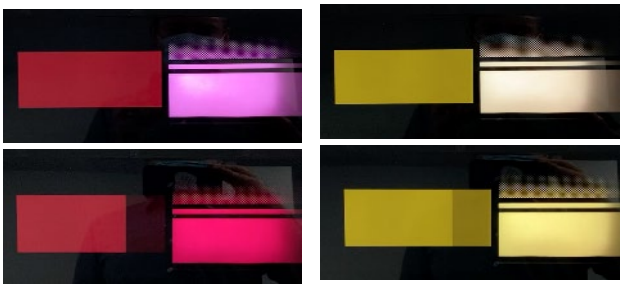

Figure 3: Color matching between an LCD display and an LED tile. First row: before processing (same RGB values, very different perception) and second row: processed with color matching

2- Energy Efficiency

Power saving, energy efficiency or greenness of a device is another key factor that has a demand from end users. In automotive, particularly with the advancements over EVs (Electric Vehicles), energy efficiency is a hot topic. Every watt saved matters. Mercedes-Benz EQXX announcement in early 2022, targets 1000 kilometers using a single charge of around 100 Kilowatts. Displays are getting bigger and there are more of them in the car and saving watts per inch of display is one of the major focuses in the coming years.

Providing display hardware designs as well as software optimization methods to save energy are among the state-of-the-art solutions to this challenge. Perceptual image processing based on the environment conditions, viewer's individual visual system and use case are amongst the new areas of focus in automotive display industry. Historically, saving power resulted in compromising image quality in the display world and nowadays with the advancements in the perceptual image processing field, we can maintain or even improve perceived image quality while optimizing for power usage by leveraging the content-aware techniques as well as physiological research that provide us with a better understanding of the key areas of an image that need to be more visible.

In contrast to conventional image processing approaches that were fixed, it has also become very popular to adjust the pixel processing occurring in the chipset or on the display driver to adapt and adjust in real time to the dynamic variables such as image frame. The figure below shows a side-by-side demonstration of such adaptive image processing on two identical displays for a side-by-side comparison [2, 3].

Figure 4: left, how todays display looks in a sunny environment without "perceptual adaptation", Right, cutting-edge perceptual processed content matching the environmental lighting conditions. The environment is measured at 15K lux.

3- UX Design and Interaction/Safety

One of the most advancing areas of R&D during the recent years has been user experience design, HMI (Human Machine Interaction), HUD (Head up Display) and safety-related topics in automotive industry. Available mass-produced display technologies in the market lack the smartness/flexibility required to provide the driver with reliable display interaction all the time.

The Content designers, display cockpit designers, and industrial designers are working closely with the UX teams to provide optimal interactions with displays. Maintaining a standard level of visibility in all weather conditions, on all display HW systems and to all individuals is a must that cannot be achieved without leveraging image processing and computer vision methods. A close collaboration between industry and research institutions on topics like object recognition & gaze tracking, on one hand, and the advancements in processors such as CPUs & GPUs, on the other hand, enable usage of AI-based image processing and computer vision solutions in the industry more than ever.

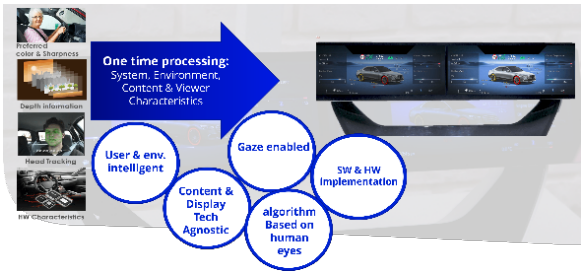

Figure 5: considering the user preference, depth information, eye/gaze information, hardware specifications and the content characteristics to build a Perceptual Display Processing (PDP) pipeline that dynamically customizes the content before rendering on the screen.

Figure 6 below shows an E-mirror (Electronic Mirror) designed with all weather conditions visibility, gaze-enabled and HW agnostic that can guarantee visibility in challenging lighting conditions such as fog, snow, rain and night. The presented C-DiVE - Camera to Display Visual Enhancement technology uses sensor information such as ambient light and rain/moist detection sensors to understand the weather condition and automatically compensate for the effect of lighting/weather. As a result, it increases visibility of the camera content shown on displays by 40%. That results in a safer interaction with the vehicle electronics for the driver or co-passenger.

Figure 6: Forvia Electric Mirror (E-Mirror)

Figure 7: Perceptual Image Processing running on E-mirror content in fog and at night.

4- User Perception/Personalization

Personalization and customization of every device and service is an expected feature nowadays. In cars, we can personalize our seat, mirror, profile & integration but not yet our displays. Our unique individual visual system justifies a new field of R&D in display industry focusing on different perceptual aspects of human vision, simulation of the aspects and potential compensation for visual degradations. Some of the most well-known visual degradations are aging and color blindness/deficiencies. Physiological studies exist in both areas but there has been no display product introduced in the market with personalized image quality.

Using the user profile, or running a 30 second preference test, we can provide the user with a personalized display viewing experience that can help with safety, visibility optimization, and even power efficiency. Available sensors, applications and user profiles can provide us with depth estimation, viewer's preferred color & contrast, viewer's area of focus or even intention.

Evangelism of Perceptual Displays

The notion of Perceptual Displays is not necessarily a new concept. 3D displays & High Dynamic Range (HDR) displays introduced back in the 2000s are examples of the impactful technical hardware advancements towards building displays that are closer to what we see in the real world [4, 5]. Although, trying to define & optimize "display user experience" leveraging physiological research has become more broadly used in the last decade [6, 7]. Nevertheless, perceptual quality, evaluation of perceptual features, subjective evaluations and user-centric approach to display design are the key differentiations of the competitors in the display industry. Just at the beginning of 2022, big display corporations introduced various software and hardware solutions solving display UX challenges using keywords such as "perceptual quality" and "perceptual display" [7].

Evangelism of any disruptive approach in the industry takes 5–7 years on average only if it is the right time for the concept to be adapted. We started evangelizing "why perception is the next big thing in the display industry" at around 2015 timeframe with the help of our technical advisors and the market has eventually caught up with the software and UX aspects of perceptual display building. We believe this is just the tip of the iceberg of Perceptual Processing in the camera and display industries and there is so much more to be done to provide display users as close of an experience like their real-life visual experience. More professors, students, and interdisciplinary research fields are required to help close the huge gap between where our display UX is today and how the perceptual displays could be built in the future. Customization, adaptiveness, dynamic changes in oppose to standardization is required to enable every display user with a unique, comfortable and healthy experience. End users (including young users such as toddlers and teenagers) are spending more and more time in front of different screens and side effects of screen time is being researched. Perceptual Display Processing considers the physiological research and know-how of "too much screen time" and provides solutions to minimize them.

Productization of Perceptual Displays

Productizing of each of the above-mentioned perceptual image processing approaches have taken between 3 to 4 years from the ideation stage. In this section, we discuss our best practices and lessons learned when we first started with the productization of our Perceptual Display Platform (PDP) technology. Below are the eight steps used by our team of multidisciplinary experts to take a perceptual idea from ideation to productization, known as "Innovation pipeline".

1- **Product Market Fit analysis:** An analysis that specifies a degree to which a future product satisfies market needs. Innovation discussions with potential customers, tradeshows, conferences and market analysis are the main activities at this stage.
2- **Ideation Stage:** At this stage, our researchers brainstorm with our Technical Advisory Board (TAB) members who are multidisciplinary experts in areas of software engineering,

image processing, perceptual processing, physiology, and display science. The most important outcome of this stage is a marriage between a particular market need and a cutting-edge research solution.

3- **Proof of Concept:** A research-based implementation of the solution is made to be used as a showing demonstration of the idea to the potential customers.
4- **Patent & Paper (publication):** Patenting the idea and publishing it is an important aspect of our innovation pipeline to make sure we get feedback from more experts, and we contribute to the academic research world.
5- **Product architecture & building:** Our software and hardware architects, review the proof of concept and design an optimized solution matching the market need, market technology availability and product pricing.
6- **MVP (Minimum Viable Product):** The first step towards productization of the proof of concept based on the design provided by system architects to get it closer to an acceptable product by the customers. The MVP is regularly shown to customers, market experts and TAB members to initiate the iteration of improving the performance and quality towards the final product.
7- **Iterations on Customer/event showcasing and feedback collection:** One of the important steps towards finalizing a product implementation is market feedback/voice.
8- **Innovation pricing exercise:** leveraging marketing expertise to run customer feedback and pricing tolerance exercises with both OEMs and end users to define a price for each product is a critical part of our innovation pipeline. Pricing should be an iterative exercise to always match the new market needs. We suggest running this exercise once a year for new products introduced in the market.

Measuring Perceptual Displays Performance

Displays operate in different viewing conditions from very dark (night-time driving) to direct sunlight resulting in challenging display viewing experience for the user. Most existing image/display quality assessment methods assume ideal viewing conditions therefore a real need for Perceptual metrics for display viewing evaluation is evangelized in the market.

One of the biggest challenges with promoting perceptual processing solutions is evaluation and quality measurement. Subjective evaluations that are vastly used in academia are not widely accepted in the industry and cannot provide a detailed objective difference between perceptual display solutions and conventional displays. In response to this need, we introduced a Perceptual Image Quality Assessment (PIQA) technology [8]. This work is an important step towards introducing a unified perceptual image processing metric as well as a platform for academia and industry for perceptual evaluation of display quality. Our goal is to standardize a perceptual metric to help OEMs specify the acceptable display visual quality and compare different solutions.

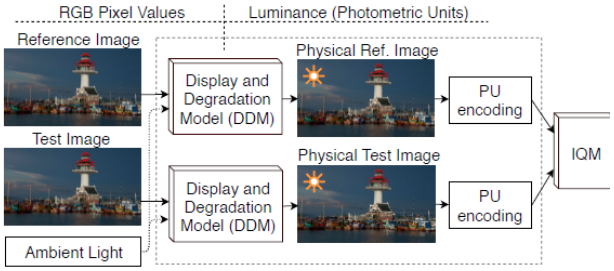

Figure 8: PIQA pipeline [8] explaining the steps for degrading the image considering the environmental ambient illumination. The same concept can be extended for age-based image degradation or any other perceptual degradation and quality assessment.

Summary

Perceptual Display Processing is a fast-growing technical field with a proven traction from end users of display-based devices and therefore manufacturers. Like any other innovative solution, Perceptual Processing also requires evangelism, market knowledge/understanding, timing, multidisciplinary team of experts, productization and evaluation to make it successfully into the hands of the end users. Smarter, more personalized, more power efficient and healthier displays can be introduced to the market leveraging perceptual display processing techniques. In this paper, we discussed automotive display market as one of the fastest growing display industries as an example to share our best practices about evangelism, productization and evaluation of perceptual display processing products. We believe this is an area for more research and development in the next few years that is attracting great investments from startup communities as well as big corporations. We would like to thank Forvia and Irystec for the support they provided to the research and productization of the Perceptual Display Platform (PDP). All products and images used in this paper belong to Forvia.

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