

PixCell LED

Ultimate precision in perfect alignment

100+ individual cells with just 25 μm spacing, perfectly matrixed onto a single LED chip for intelligent headlamps

SAMSUNG



Editorial

ISAL: Five Takeaways About The Vehicle Lighting World



A group of us from the DVN team—Wolfgang Huhn, Michael Hamm, and I—went to ISAL in Darmstadt along with 750 other attendees last week to see the presentations and exhibitions of the latest innovations and trends from the German perspective. I mentioned Germany on purpose, because around 2/3 of the attendees were from Germany. The second-biggest delegation was from Korea, and less than 10 from China, Japan, or North America.

These figures show five things about the world of vehicle lighting:

- Germany remains at the heart of lighting innovation.
- Korea has grown a lot, pushed by Hyundai-Kia and the Korean supplier ecosystem—SL, Hyundai Mobis, Seoul Semiconductor, Samsung...
- As usual, the U.S. is off doing its own thing, focused on trying to see if any good can be wrung from NHTSA's ADB rule. The major UAW strike could also explain the low level of attendance.
- Japan is still strong, but sent fewer attendees than Korea. Less things to learn or less things to demonstrate?
- China: ISAL was just the week after ALE, with its 30,000 attendees and just before mid-autumn festival. But that is not the only explanation for the low Chinese attendance at ISAL. China has now its own market, with a lot of innovation attractive to Europeans, while there's less for China to come see in Europe for lighting technology. This is clearly an effect of China being the world's biggest and fastest-growing auto market.

Next week we'll bring you, in our monthly report, a thorough summary of ISAL. In this week's DVNewsletter, we present two insights:

- ams OSRAM interview about the best innovative concept of the week for me, their amazing Aliyos which is sure to make fast friends with designers
- Interview of Katrin Schier from Forvia, whose lecture was selected as the best of ISAL this year.

On the road to ISAL, I also took time to visit the Lotus Tech Innovation Center in Raunheim and made an interview with their exterior lighting technical lead, Frank Langkabel. You'll find that interview in this week's news, too.

We're glad you're with us!

MATHA Paul-Henri
DVN COO and General Lighting Editor

In Depth Lighting Technology

Lights are Central to Lotus Eletre's Emotional Appeal



Lotus participated in the US DVN Workshop in August, and made a really nice presentation. It was the first time for DVN to welcome their lighting group on the stage. In reciprocity, we visited their office in Raunheim to talk with their lighting team about Lotus lighting technology and interview Frank Langkabel, their exterior lighting technical lead.

Driving Vision News: Frank, tell us about your company.

Frank Langkabel: Lotus is now part of the Geely group who has a large portfolio of brands. Lotus is at the top of the pyramid when we talk about luxury and sport.



Geely portfolio

DVN: For me, Lotus is an English car maker, but you are located in Germany.

F.L.: Lotus has different locations for R&D, design and manufacturing. If we focus on R&D, it is split between the UK, Germany, and China.



DVN: Thinking back now on your presentation in San Francisco during the DVN Workshop: Rouven from your team started with some slides about the Lotus heritage—three nice cars for me. I am a James Bond fan, I was born in 1977, and I really like pop-up lamps. Already Lotus was quite innovative when we talk about lighting!



Then, you presented some details on the lighting concept of the Lotus Evija, launched in 2019. The Lotus lighting pedigree is impressive: laser low beam, laser high beam! **Can you give us more details about the low beam and high beam concept?**

F.L.: You are right. The Evija is the first production road car in the world to feature laser lights for both main light functions. Six Osram lamp modules—four modules for the low beam and the remaining two for the high beam—are positioned to reflectors and microlenses. Each of these six module lenses is 20mm high and 17mm wide.





DVN: The rear lamps also have an amazing design with a 3D shape integrated in the body. How is the lamp integrated in the car? is it a carbon-fibre body?

F.L.: Yes, the Evija has a lot of carbon parts. The rear body air tunnel is a 2-piece carbon construction with the lamp being flange mounted to the tunnel before the second half is assembled. Then the whole module is assembled to the vehicle.

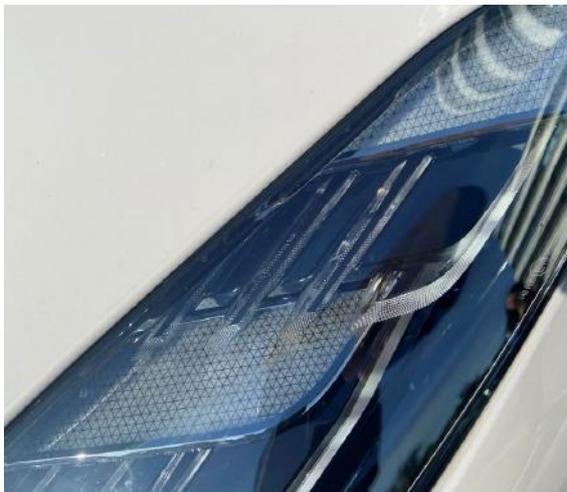
DVN: Part of your DVN Workshop presentation was dedicated to the new Lotus Eletre. So many interesting concepts on the car! **You mentioned that you have L⁴ Hardware set up, ready for OTA activation. Could you give us more information about the hardware on the car?**

F.L.: That's right, the Eletre is equipped with L⁴ Hardware. In total there are four Lidars, six radars, 11 cameras, HD mapping, and two redundant Nvidia SOC computers in the vehicle.

DVN: Speaking about headlamps, I remember two things: an innovative hot foiling concept for signaling function and some very thin lighting functions with very high performance (500-metre range for high beam). Could you provide us some more detailed information?

F.L.: Regarding the hot foiling solution: the big challenge was to respect the boundary conditions needed for the hot foiling process right from the beginning within the design phase. The foiled areas have a width of only 3 mm. The definition and refinements of the blackout areas required some iterations with together with our designers to achieve the best possible result and a very clean appearance of the foiled areas.

In addition, the development of the right foil also played a crucial role in order to block all the light with it. By the way, we are now rolling out that hot foil execution also to the Emeya, our new electric grand tourer.



You are right, the headlamp is very slim with an overall height of not more than 65 mm for the light exit window. We managed to package three modules inside with light emitting surface heights ranging from 30 - 35 mm. The key to the high intensity for high beam was to implement parts of the high beam function into each of these three modules. One of those modules is the very unique high beam -spot / cornering lamp module for which we developed the general concept in-house.



DVN: The rear lamps are very well integrated in the car. You integrated an EV charging indicator in the lamp. Is it done with dedicated monocolour led, or is it RGB leds...?

F.L.: Yes, the charging indicator function is given by more than 80 RGB LEDs in the centre area of the rear lamp. They provide different graphics in terms of displayed width and slight changes in color, based on the state of charge provided from the vehicle's battery management system.

DVN: Do you have some customer feedback about this nice feature? How is it perceived compared to the usual LED indicator, smaller than 1 cm² we see on other cars?

F.L.: The beginning of this year, the Etre was launched in China. During the launch event in Oslo the feature was very well perceived and often mentioned by the media. With the first deliveries to our EU sales network a couple of weeks ago and with customers admiring the Etre in our dealers' showrooms, this feature plays a significant role in the overall experience and emotional aspect for our customers. It is something they've never seen before, and that is what we wanted to achieve.



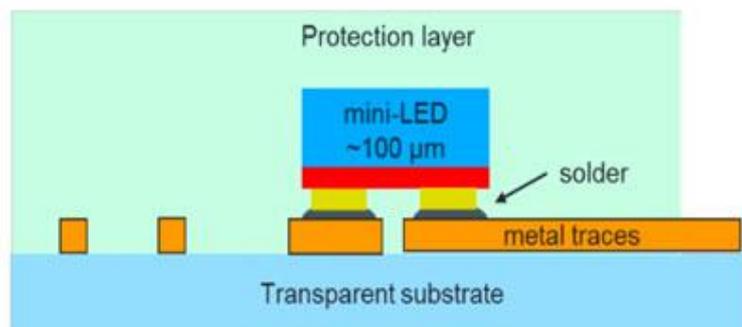
Lighting News

ams OSRAM's LED-on-Foil Makes 'Light Out of Nowhere'

LIGHTING NEWS



At ISAL last week, ams OSRAM introduced their new Aliyos™ technology: a thin, transparent, 2.5D-bendable foil for creating customized, multi-segment, adaptive, 3-dimensional lights and invisible-when-unlit lights on curved panels.



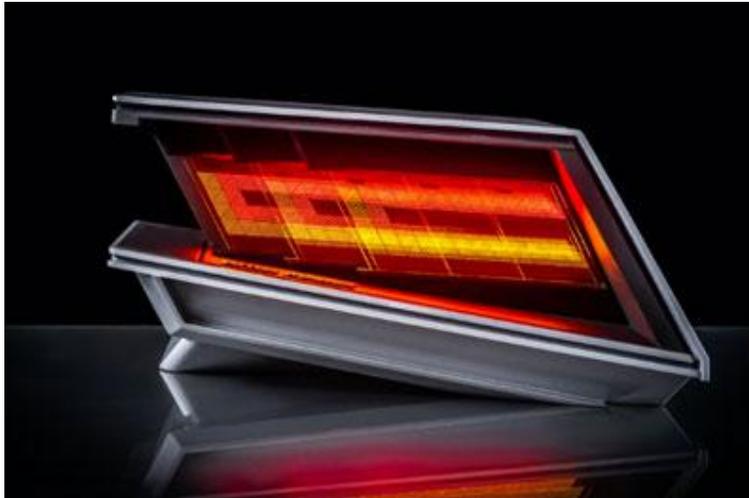
MiniLEDs are assembled onto a thin transparent substrate (the 'foil'). Thin metal traces on top of the substrate are used for current-spreading within the segments, and as contact pads for the miniLEDs. Typically, several miniLEDs are connected in series within one string and several such strings, in turn, are connected in parallel to fill the segment area. The number and position of the LEDs and the corresponding wiring has a large degree of freedom, and so can be used to form individually-addressable segments of any shape. The flexible LED foils can be part of a transparent stack, or applied behind translucent materials.



This enables revolutionary designs and on-demand features. Connected by almost invisible metal traces, the mini-LEDs can be arranged with a large degree of freedom to form individually addressable segments of any shape. They can be positioned to perform standard

lighting functions such as a stop light or turn indicator, but with unique, custom shapes and animation effects. The mini-LEDs can also be used to display symbols, words, images or abstract patterns for decoration, information, or warning. Multiple foil assemblies can be placed one behind the other to create dramatic new 3D lighting and animation effects.

For the ISAL presentation, ams OSRAM built two rear combination lamp prototypes: an ultra-thin 2.5D curved one, and a transparent one with 3-dimensional design. Both prototypes feature customizable tail and stop light functions as well as turn signals with 256 and 384 addressable segments, respectively. The prototypes more than meet the UN R148 requirements for the luminous intensity of the stop, tail, and turn signal functions.



You can use it like a film, you can bend it, it can be homogeneous with an additional diffusive element, it can be pixelated, it can have a display appearance. A lot of new possibilities and for sure a lot of interest for designers and stylists! Industrialization of the technology has begun. The aim is to enable the first cars to be equipped with Aliyos lights by the end of 2025.

This new concept was one of the major innovations released during ISAL, and the DVN team took time to discuss it with Manuel Walch, ams OSRAM automotive signalling product marketing manager:

DVN: You mentioned 2025 for SOP. Will you start first with red colour, or both red and yellow? And what about white color for DRL, front position, and reversing lights?

Manuel Walch: In the first generation we will have red and yellow available. White will follow shortly thereafter with the second-generation Aliyos.

DVN: What about optical performance, what luminance can you reach? What's the power consumption and efficacy like?

M.W.: The achievable luminance depends on the colour and the forward integration of the Aliyos foil in the customer's solution. Brightness levels greater than 10,000 cd/m² are possible. Power consumption depends on the customized design, including number and shape of segments, and on the segments' brightness level. To get an idea: in our own demonstrator, we would be able to fulfil the stop light function with ~10W power consumption for the array of three Aliyos LED foils mounted one behind the other.

DVN: How about integration, how will you connect this film to the lamp harness? What can you say about qualifications like AECQ-102?

M.W.: The forward integration is something we are discussing with the tier-1s and OEMs. Our target is to qualify the Aliyos LED-on-foil technology for automotive exterior. I ask for your understanding that we don't share details at this time.

DVN: Have you also considered how your Aliyos technology will work in terms of the EPLLA (effective projected luminous lens area) requirements in the USA? Will it go by pixel surface or film surface?

M.W.: For sure we will consider together with our customers the legal requirements and have to pass legal values and tests.

DVN: Thank you, Manuel, for the interview. This is amazing technology!

Hella's Katrin Shier Wins ISAL Best Lecture Award

LIGHTING NEWS



Katrin Shier was born in Jena in 1988 and studied Electrical and Information Engineering at the Karlsruhe Institute of Technology (KIT). She received her Master's Degree in 2014 with the focus on optical technologies. And in 2015 she joined Hella as a development specialist for image processing algorithms for fully automated adjustment processes and quality control in headlamp production. At the beginning of 2020 she started her PhD project at the Laboratory for Automotive Lighting and Mechatronics (L-LAB) on the topic of luminance non-uniformity evaluations in headlamp light distributions. Since March 2023 she is employed as a pre-development specialist for human perception.

At the end of the ISAL congress, Katrin received from Wolfgang Huhn the award of best lecture, given by the steering committee and the audience. Because this lecture was in the parallel session in ISAL, and because it seemed to have great interest, we proposed to Katrin to write a synthesis for our newsletter, that you can find at the end of this newsletter, and she graciously agreed to this as well as our interview.

DVN: Why did you choose to study this topic of “Enhancement of a Contrast Threshold Prediction - Model by the Implementation of the Dual Tree Complex Wavelet Transform”?

Katrin Shier: As a development specialist for image processing methods for automated in-line testing, non-uniformity evaluations were always a topic my team and I had to tackle. Converting the task a human can do without great effort into image processing algorithms did not succeed as a generalized approach. The evaluations were product specific and hence had to be re-developed for specific products. This made me curious about why the task is so difficult and triggered the ambition to tackle the problem. Additionally I believe that the human visual system is really fascinating and choosing the topic as a PhD thesis gave me the opportunity to dig more deeply into the details.

DVN: What are the next steps after your results?

K.S.: The model is not complete, as vision is very complex. There are a few features missing that cannot be simulated by the model today. It is my goal to tackle these problems in the near future, so the algorithm can be implemented for evaluations. Additionally we need excessive testing with our products and compare the results to human observers, to verify and prove that the approach is truly generalizable to different product families.

DVN: Do you want to use your results to improved your simulation tool? are current rendering software’s packages not enough today to simulate this homogeneity?

K.S.: Once verified the model should help us at a very early stage in development. So using the model as an additional tool in our simulation software is one of the targets. If we have a rendered luminance image as output from a software tool we can take a look at the image and evaluate the non-uniformity in a subjective manner, but the result is not quantified. The evaluation result will thus vary between observers and even vary for a single observer, depending on the images the person viewed directly before the evaluation. Studies measuring human visual performance hence always randomize the order in which they show the images, to avoid measuring these biased effects. Additionally the result will differ with the monitor which is used to view the result. In my opinion a visual inspection is a good evaluation for a first step. However, quantifying the uniformities in a reproducible manner is very important in the development process. The model could thus be seen as an add-on that can be used to enhance the evaluations of the rendered images.

DVN: Based on your results, can automakers define a specification for homogeneity criteria which is always difficult, especially when the surface is not homogeneous?

K.S.: Once verified the tool will help us understand and predict critical non-uniformities. I strongly believe we can hence use it to define quality measures that can be implemented into specifications. At this point further discussions with stakeholders are necessary for a wide spectrum of applications. It is not an easy task and will not be finished tomorrow. But the results are promising and I am hoping for further discussions with the automotive lighting community.

DVN: Do you think you can improve the end-of-line camera measurement with your results to control that the lamp is conformed with the specification before delivery to customer?

K.S.: Currently the created software is still very complex and computationally expensive. With all the extensions which I have mentioned before it will not get easier. So today the software cannot be simply implemented into the end of line testing. Short cycle times are vital for these machines. Once the algorithm is fully verified, we will start working on simplifying it and making it faster. This will be a hard task, but I strongly believe that this is possible. However, we should not confuse the EOL test with a machine that is used to qualify our products. It is a tool which is used in production to ensure the monitoring of the stability of the production process. If we can make sure that the product we are building fulfils our customer's needs and we can ensure a fully stable production process, we will not have to do all the complex evaluations that are indispensable during the development and approval phase

DVN: Thank you Katrin for the interview and the time you spent to answer questions. It is a promising tool and I wish you a great career at Hella!

You will find the condensed digest of this lecture written by Katrin Shier at the end of this newsletter.

Bernard Schäferbarthold is New Hella CEO Appointee

LIGHTING NEWS



Bernard Schäferbarthold, currently Chief Financial Officer of Hella, will become the company's new Chief Executive Officer. This was decided by the Shareholder Committee at their recent meeting.

Schäferbarthold will take over the post on 1 January 2024 from current CEO Michel Favre, who has mutually agreed with the Shareholder Committee on an early termination of his mandate.

Schäferbarthold, who has signed a long-term contract, has already been a member of the Management Board responsible for Hella's finance and controlling corporate function since November 2016. He will continue to be responsible for the CFO role in combination of tasks, until a successor is appointed. He says "Hella will celebrate its 125th anniversary next year. To be able to take over the management of a company that is both rich in tradition and future-oriented is a great honor for me. With Forvia, we are now a global leader, more diversified and less exposed to risks. I'm looking forward to taking our combined expertise to the next level and continuing our successful course together with all colleagues worldwide for the benefit of all shareholders. I want to help accelerate the pace of innovation, consistently strengthen autonomy in the various regional markets and further expand our leading position".

Gerald Mentil is New President, CEO of PO Lighting

LIGHTING NEWS



Gerald Mentil, a member of the Executive Committee of Plastic Omnium since last May, has taken on the position of President & CEO of the Lighting Division, replacing Stephane Noel.

This division dedicated to vehicle lighting was created in October 2022, allowing the Group to be present throughout the lighting value chain and to meet the growing demand from manufacturers for integrated exterior systems.

Mentil brings a wealth of automotive and international experience; he spent his entire career in the automotive industry within the Forvia Group, where he held various management positions worldwide covering Europe, Asia, Americas, and Africa, such as VP of Emerging Markets, VP of Global Operations and Quality and, more recently, VP of Seating Components.

New Lotus Flagship Brand Centre Opens in Paris

LIGHTING NEWS



Lotus have opened the doors of a new flagship store in Paris, located in the famous 'Golden Triangle' area of the world's fashion capital. It is in the perfect city centre location amongst other luxury and haute-couture brand boutiques.

Following on from high-profile openings in London, Munich, and Oslo, the new store in Paris brings together Lotus' long-standing commitment to technology, performance and heritage by providing customers with an exclusive and immersive entry into the brand. Lotus Paris offers three floors dedicated to the brand's past, present, and future. The ground floor serves as a street-level walk-in showcase and launch venue for the next-generation vehicle line-up —the Eletre SUV, Emira sports car, Evija hypercar, and Emeya GT.

Lotus started customer deliveries of the Eletre in Europe and has this month expanded their business across the continent, launching new commercial operations in Denmark, Austria, and Luxembourg. With the addition of these three new countries, Lotus are now represented in 12 markets across Europe.

For the opening of the store in Paris, Lotus and digital artist Ksawery Kirklewski have united their talents and passions for retro-futurism to craft an immersive illuminated experience. Their collaboration has delivered an LED techno-chromatic spectacular around an Eletre with the brand centre.

Hella at Busworld: Innovative Lighting for Transit Buses

LIGHTING NEWS



Marcopolo G8 headlamp from Hella

At this year's Busworld 2023 in Brussels, Hella will be presenting customer-specific innovations for city buses and coaches. Held every two years, Busworld is the world's largest and oldest trade exhibition for the bus industry.

One of the highlights of Hella's presence at the trade fair is LED headlamps, which Hella have put into series production for the new G8 coach series of Brazilian bus manufacturer Marcopolo. The headlamp features Hella's largest one-piece LED reflector. This makes for a striking appearance, as the headlamp is not composed of several individual parts, but appears to be cast from one piece.



The SlimLine Bi-LED headlamp is not only powerful and robust, but above all sets new standards in design. As the first rectangular light module in the Hella portfolio, it follows a highly topical design trend that is also becoming increasingly popular in the bus sector. The SlimLine module combines low- and high beam in a single module.

Driver Assistance News

Mercedes to launch L3 Tech in Western U.S. in Q4

DRIVER ASSISTANCE NEWS



Mercedes-Benz will launch their L^3 automated driving technology in California and Nevada in the fourth quarter.

The service, approved for use in California and Nevada, will initially be available in a limited number of Mercedes' electric EQS sedans. Next year, Mercedes will expand the Drive Pilot technology to their gasoline-powered S-Class sedan. Drive Pilot will be available as an annual subscription, priced from \$2,500 in the first year.

Mercedes' Drive Pilot system allows the car to take control of driving functions under certain conditions, freeing the driver to do other things, such as answering emails. But the system can ask the driver to take control at any time, a prerequisite for L^3 autonomy. If the driver does not respond within 10 seconds, the car will come to an emergency stop.

L^3 is approved to operate on highways at up to 60 km/h, meaning its primary use would be in congested traffic or traffic jams. Drive Pilot uses radar, lidar, cameras, ultrasound and moisture sensors to provide data on road conditions to vehicle computers. It controls speed, braking and lane position.

Nio Show Full-stack Technologies & R&D Capacities

DRIVER ASSISTANCE NEWS



Nio Full Stack is a collection of technologies encompassing 12 domains including Assisted and Intelligent Driving, Smart Cabin, Smart Power, Connectivity, Vehicle Operating System, Vehicle Engineering, Chips and Smart Hardware.

The Chinese automaker released their first chip product for lidar, providing stronger supports to vehicle's performance in complicated scenarios. Its highly integrated design with lower energy consumption and higher performance makes the chip a leading product.

Nio has been committed to the in-house development of a smart, safe and high-performance electric drive system (EDS). With their proprietary EDS technologies, Nio can realize greater flexibility in the supply chain and product design, which helps shorten development cycles and realize better product compatibility and faster iteration.

They also launched Nio Link, an all-scenario connectivity technology centering around vehicles. With integrated software and hardware, terminal-cloud coordination, a safe and open connectivity technology system, the integration of various devices is realized, including the Nio Phone. It is designed to enhance the users' connectivity experience with cars.

Also on the innovation list: a digital cockpit operating system oriented by user experience and characterised by considerate details and expandability, to create intelligent, entertaining, and eco-friendly cockpits for global users. The associated app store creates an ecosystem which covers various types of services and contents.

The Nio Phone seamlessly connects with Nio's smart electric vehicles. Its UWB technology replaces traditional car keys. Pressing the Nio Link button on the left of the phone will switch on the car control card for intelligent operations. Additionally, the Nio Phone can automatically switch to in-car mode, intelligently adjusting the seat position and AC settings based on where you sit.

General News

Auto Industry Rejecting Globalization

GENERAL NEWS



Extract from Les Echos

After supply disruptions, manufacturers are drastically shortening their logistics chains. Just-in-time and finding the supply of parts on the other side of the world to save a few cents is no longer the target of the automobile industry.

The sector is relocating in masse, notes Capgemini in a study published in recent days. “The proportion of supplies coming from distant countries has fallen by 22% over the past two years,” the authors write. They expect an additional decline of 19% over the next two years. The automotive supply chain has had a very difficult time coping with the full-scale stress test of the pandemic. The combination of just-in-time, shortages and serious disruptions in port transport of goods during the years 2020 and 2021 have overcome the canons of the industrial organization model invented by Toyota in the 1960s.

Therefore, direction on the relocation of supplies. “This is a strategic objective for us,” explains the manager of an automotive group cited in the study. Given political pressures and questions of availability of raw materials, 75% of our supply chain must be repatriated to countries close to our factories, or even next to them. » Cost difference Europe leads the way. Automobile manufacturers and industrialists have reduced their supply by a quarter.

“Sourcing in Europe or closer to the Old Continent is naturally more expensive than manufacturing in China, but offers more flexibility in supply and therefore better risk management,” explains Alexandre Audoin, in charge of automobiles at Capgemini.

Taking the lead, equipment manufacturer Bosch announced in June 2021 that it was investing €1.2b in a semiconductor and sensors factory in Germany. Not to mention the investment of €30b by Intel across the Rhine to produce chips. However, getting these sites up and running will take time. Improving resilience Asia-Pacific and the United States are following the trend. For the latter, this is also reflected in the import figures, those from China having decreased by 24% in the spring. A trend that clearly benefits Mexico, where auto manufacturers have become among the first foreign investors, according to the government. The powerful American regulations have nothing to do with it. The industrialists interviewed by Capgemini are categorical. They believe that, thanks to relocations, they would be able to avoid 60% of the costs caused by logistical disruptions they suffered in 2022.

New Stellantis Architecture to Cut Processor Count

GENERAL NEWS



The new Stellantis platform design includes a ground-up design for vehicle electronics and includes semiconductors from the SiliconAuto JV with Foxconn. This comes after Stellantis CTO Ned Curic highlighted the need to cut the number of chips. "Right now in vehicles, there are 50 to 120 electronic control units. We are looking to centralise the architecture with high-performance computing and zone controllers with a significant reduction in edge devices. The current architecture for most vehicles is almost entirely edge devices. We want to use AI and other methods to centralise the architecture. The algorithms want to get access to the raw signals so we want to centralise the data", said Steve Rober, Senior VP and Global Head of Advanced Electronics & Semiconductors at Stellantis.

This simplification changes the vehicle architecture significantly. This will require high-speed Ethernet networks throughout the vehicle rather than the current CAN bus implementations, with controller chips in each of probably four zones in the vehicle feeding into a central AI processor.

This simplifies the sensors and the software development and builds on the acquisition of Hungarian AI technology developer aiMotive last year, which has developed hardware and software IP to add into automotive chips from Nextchip in Korea. This starts with Level 2 advanced driver assistance systems (ADAS) that are easily upgradeable to Level 3 and then to Level 4 autonomous driving.

The designs are slated to come onstream within the next few years.

Lighting News

Best lecture at ISAL 2023: Condensed Digest by Katrin Shier

LIGHTING NEWS



Enhancement of a Contrast Threshold Prediction Model by the Implementation of the Dual Tree Complex Wavelet Transform

The uniformity of a luminance distribution is directly connected to the quality perception of the light emitting device. This is true for light patterns created by headlamps that are reflected by the road surface as well as for rear lamps or light emitting decorative elements that are viewed directly. Non-uniformity is especially critical for large light emitting surfaces. There have been several proposals in the past for measuring and quantifying the phenomenon to enable a reproducible and objective quality control. However, these evaluations are very application dependent. One reason for this is the complexity of human contrast and brightness perception. The example of how the surround of a stimulus can severely influence the perception of brightness is shown in fig. 1. The left image shows a pattern consisting of connected diamonds with a luminance distribution. For an observer the

right side of the pattern is perceived darker than the left side of the pattern. The measured luminance distribution however is the exactly the same for all diamonds in the pattern. This effect suddenly disappears if only the central row of diamonds is kept and the rest is removed.

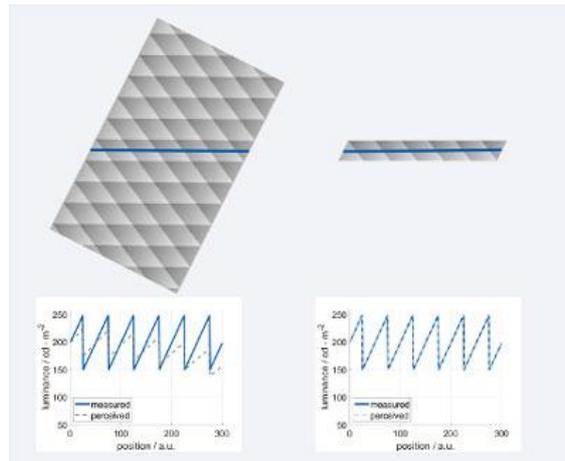


Fig. 1: The perceived brightness along the blue line differs between the left and the right pattern. The change in brightness perception is caused by change of the regions that surround the profile.

The perception now correlates better to the measured luminance. This example clearly demonstrates the evaluations of luminance profiles should not be used to evaluate non-uniformities of light distributions, as they do not always correspond to the perceived brightness. We have recently published a model that simulates the first processing steps of human contrast vision to overcome this problem. An overview of the model is shown in fig 2. It takes spatially resolved luminance measurements as input and consists of three sub-modules that are connected in a serial manner: First the influence of the optics of the eye is calculated with an optical modulation transfer function proposed by Watson. Then the neural contrast processing is simulated. The last sub-module is a contrast threshold prediction model. The image is reconstructed by only keeping the elements that exceed the contrast threshold.

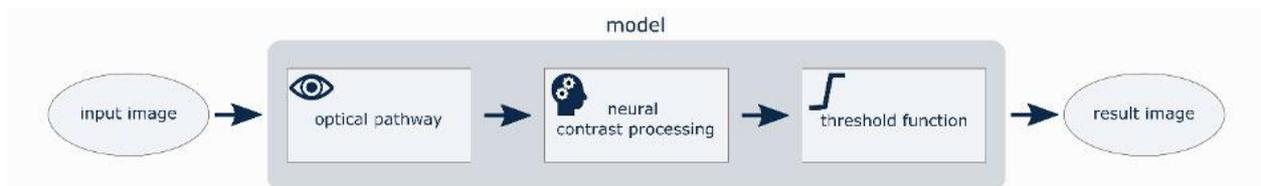


Fig. 2: Proposed model for simulating the contrast perception of the human visual system

The neural model uses the method proposed by Peli to calculate the bandlimited contrast. For this isotropic log-cosine filters are convoluted with the image signal by a multiplication in the Fourier domain to split it into separate spatial frequency channels. For luminance distributions of mesopic environments the reconstructed image shows large distortions. The reason for these distortions is that high spatial frequencies are not visible to the human observer in mesopic environments. They are thus locally removed by the model, dependent on the local adaptation. However, the implemented Fourier transform approximates the signal with infinitely long functions. Therefore spatial frequency cannot be localized in the image. When taking out parts of the signal visible distortions are created. Hence, a solution for this problem has to be found.

When taking a look into the signal processing toolbox we find the discrete wavelet transform as a solution for localizing spatial frequency. The transform uses spatially localized functions to approximate the signal. Fig. 3a shows the schematic for the discrete wavelet transform as proposed by the well-known fast discrete wavelet transformation algorithm as proposed by Mallat. For each decomposition level the signal is convoluted with a high-pass and low-pass filter first for the rows and then for the columns. The result is down sampled by a factor of two after each convolution operation. The decomposition results in three orientations for each level of filtering. The lowpass residual (LL, filtered with low pass in both directions) is then used as input for the next level. The discrete wavelet transform is not shift invariant.

This can cause a shift of the energy in the wavelet domain, leading to a wrong band-limited contrast calculation when shifting the image spatially by just a few pixels. Therefore this transform cannot be applied for calculating the band-limited contrast. It would lead to a wrong evaluation of the contrast. To overcome this problem the Dual-Tree Complex Wavelet Transform (DT-CWT) was introduced by Kingsbury. Here the fast discrete wavelet transformation algorithm is extended by adding a parallel second tree (see fig. 3b, shaded yellow part). This second tree is considered to carry the imaginary part of the signal. If the wavelets of tree one and tree two are designed carefully, an analytical signal can be approximated by this transform. This is given if the wavelets of tree two approximate the Hilbert transform of the wavelets of tree one. The transform splits the signal into spatial frequency channels with a bandwidth of one octave and into six orientations (three from each tree). The impulse response of the filters of the DT-CWT resemble the receptive fields of the simple cells of the primary visual cortex. Thus, in addition to the localization of spatial frequency, the model is enhanced by simulating higher processing stages of the human visual system than with the log-cosine filters used before.

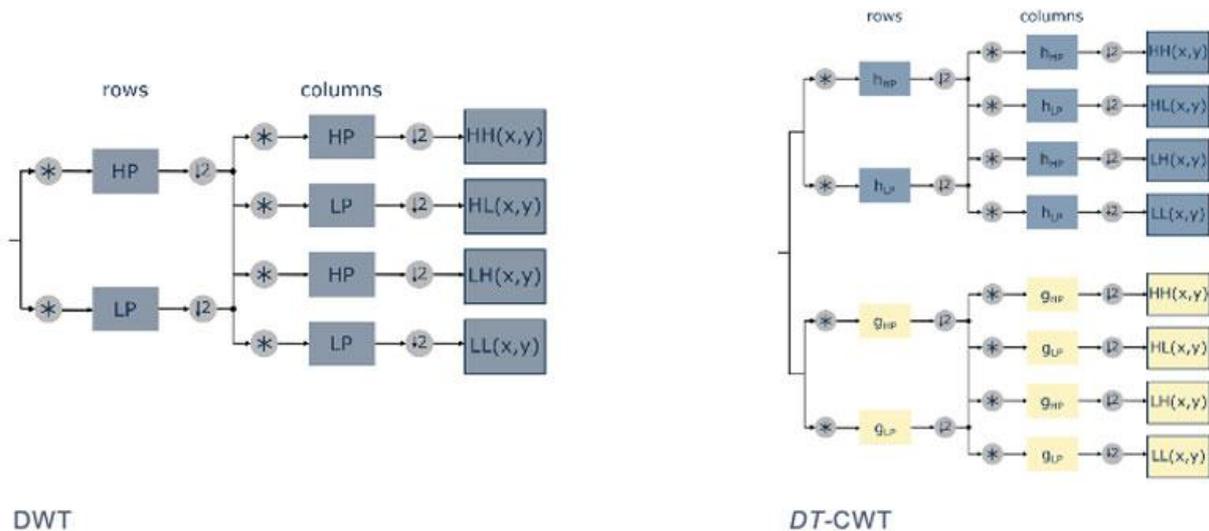


Fig. 3: Schematic for one level of the two-dimensional discrete wavelet transform (DWT) using the algorithm proposed by Mallat and the Dual-Tree Complex Wavelet Transform (DT-CWT) as proposed by Kingsbury

To evaluate how the calculated contrast value changes with the exchange of the filters, a comparison to a ground truth Michelson contrast has to be conducted for the contrast calculated with both filter types. For this sinusoidal test gratings with a Michelson contrast of $c_M = 0.1$ containing a single spatial frequency were simulated. For each of the spatial frequencies (0.5 cycles per degree (cpd) to 16 cpd in octave steps) 100 measurements of the contrast were conducted using both filtering methods. The results show that the contrast calculated with the Dual-Tree Complex Wavelet Transform is reduced for larger spatial frequencies. However, the deviation does not exceed 5% of the ground truth contrast. This is an acceptable value for contrast vision, as inter-individual differences of measured contrast sensitivity of human observers are large. When comparing the calculated contrast for square wave gratings the contrast calculated with the log-cosine filters shows overshooting at the transition between bright and dark for the log-cosine filters. This is not the case for the wavelet filters (see fig. 4). Hence in this case the DT-CWT lead to a significant improvement of the contrast calculation.

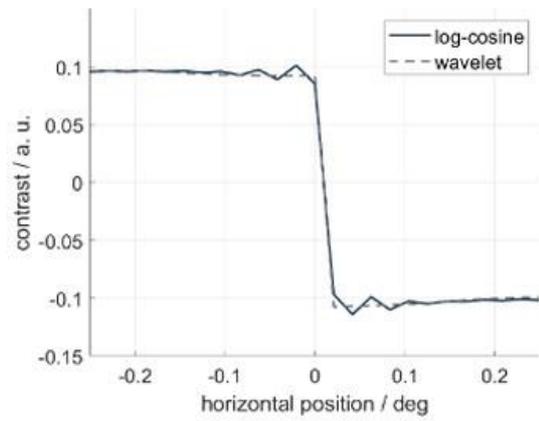
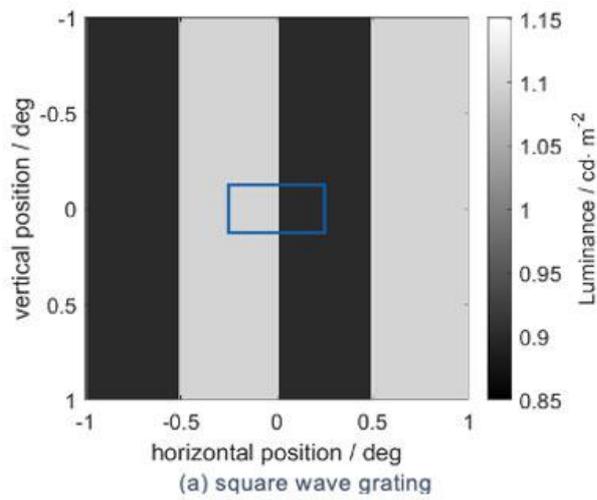


Fig. 4: Comparison of contrast calculations for square wave gratings. The contrast calculation with the log-cosine filters shows large overshooting at the luminance step.

Fig. 5 shows a visual comparison of the model results of the reconstructed image for both filters. As the luminance image contains low luminances, the signal parts containing high spatial frequencies are removed from the signal. The visual comparison shows the significantly reduced number of artifacts in the reconstructed image.



Fig. 5: Comparison of the reconstructed original image for the log-cosine filters and the DT-CWT filters.

The above shown evaluations thus verify that the DT-CWT significantly enhances the model especially at luminance discontinuities, while showing a neglectable deviation for periodic single-frequency variations of the luminance.