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IEEE-SA White Paper

IEEE P2020 Automotive Imaging White Paper

**Authored by
Members of the IEEE P2020
Working Group**



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IEEE P2020 Automotive Imaging White Paper

Abstract

The IEEE-SA P2020 working group on automotive imaging standards was established in order to address the considerable ambiguity in measurement of image quality of automotive imaging systems, both human and computer vision based. This white paper outlines the goals, achievements, rationale and plans of the subgroup, which has started to work on development of a new standard.¹

Image quality plays a crucial role for both automotive viewing and automotive computer vision applications and today's image evaluation approaches do not necessarily meet the needs of such applications. Currently there is not a consistent approach within the industry to measure automotive image quality. The IEEE P2020 working group is attempting to remedy these deficiencies by connecting people in the field, identifying gaps in existing standards, and working to address these by creating a coherent set of key performance indicators by which camera systems and components may be evaluated in a manner consistent with their intended use. This white paper provides an overview of current activities including initial gap analysis and details of what may be expected from the full standard when published.

Acronyms and abbreviations

The following list of acronyms and abbreviations will be useful when reading this white paper:

ADAS	advanced driver assistance system
ADC	analog to digital converter
AEC	automatic exposure control
AI	artificial intelligence
AWB	automatic white balance
CaaS	car-as-a-service
CDP	contrast detection probability
CFA	color filter array
CMS	camera monitor system
CPIQ	camera phone image quality (as used in IEEE Std 1858-2016 [5])
CRA	chief ray angle
CSP	color separation probability
DR	dynamic range
ECU	electronic control unit

¹ For information on IEEE P2020, please visit <http://sites.ieee.org/sagroups-2020/>

FoV	field of view/vision
FUN	Fidelity, Usefulness, and Naturalness
GDP	gross domestic product
HDR	high dynamic range
IQ	image quality
ISP	image signal processor
JND	just noticeable differences
KPI	key performance indicators
LTM	local tone mapping
MTF	Modulation Transfer Function
OECF	Opto-Electronic Conversion Function
PWM	pulse width modulation
QE	quantum efficiency
QoE	quality of experience
RVC	rear-view camera
SAE	Society of Automotive Engineers
SNR	signal-to-noise ratio
SVS	surround-view system
VGA	video graphics array (definition of a 640 x 480 resolution display)

Overview

Telephones were once for talking, and cars were once for driving. Things have changed. Mobile phones are now ubiquitous digital assistants with cameras, sensors and extensive connectivity; while cars are on the verge of becoming multi-sensor, multi-camera, multi-modal autonomous artificial intelligence (AI) platforms. There are a number of factors that drive this dramatic evolution of our vehicles—most notably, the ability to improve safety, enable more efficient urban plans, and create new disruptive business models. The key driver for this dramatic evolution in our vehicles is to increase safety.

The World Health Organization recently noted that more than 1.25 million people worldwide die each year as a result of road traffic accidents and between 20 and 50 million more people suffer non-fatal injuries, with many incurring a disability due to their injury. This results in considerable economic losses to both individuals and their families and to nations as a whole, which equates to approximately 3% of gross domestic product (GDP) for most countries [1].

Advanced sensing will allow closer proximity inter-vehicle travel distance than human-controlled vehicles, reducing the necessary lane width and freeing up space for wider sidewalks, bike lanes, and other amenities. As cities transition away from ordinances that require large amounts of land to be used for parking and circulation, they will need to determine how best to make use of that freed-up space through new approaches of land use and zoning (American Planning Association [2]). Furthermore, the transition to autonomous vehicles brings significant opportunity in terms of new mobility business models (Gao et al. [3]). Car-as-a-service (CaaS) also will provide car mobility services for a large portion of the global population (Business Wire [4]), since no driver's license is needed, and it will prove to be an affordable transportation solution.

While cameras are crucial for a vehicle to sense and perceive its surroundings, to date there has not been a consistent approach in the automotive industry to measure image quality.

There is an existing standard for mobile phone camera image quality—IEEE Std 1858 [5]. This standard, however, is generally not applicable to automotive requirements, and additionally other image quality standards, such as EMVA1288 [6] or ISO 12233 [7], fall short for when it comes to automotive image quality use cases. Automotive imaging imposes unique challenges due to its varied and distinct landscape of imaging conditions (fish eye, multi-camera, high dynamic range (HDR), temperature range, etc.), which are not adequately addressed in existing approaches. Therefore, the IEEE P2020 working group [8] has set the goal of shaping relevant metrics and key performance indicators (KPIs) for automotive image quality, enabling customers and suppliers to efficiently define, measure, and communicate image quality of their imaging systems.

Image quality (IQ) plays a crucial role for both viewing and computer vision applications. Figure 1 shows a generic architecture of a multi-camera automotive system. In contrast to industrial machine vision systems, automotive camera systems must deal with unconstrained environments, i.e., a wide range of weather, illumination, and temperature conditions.

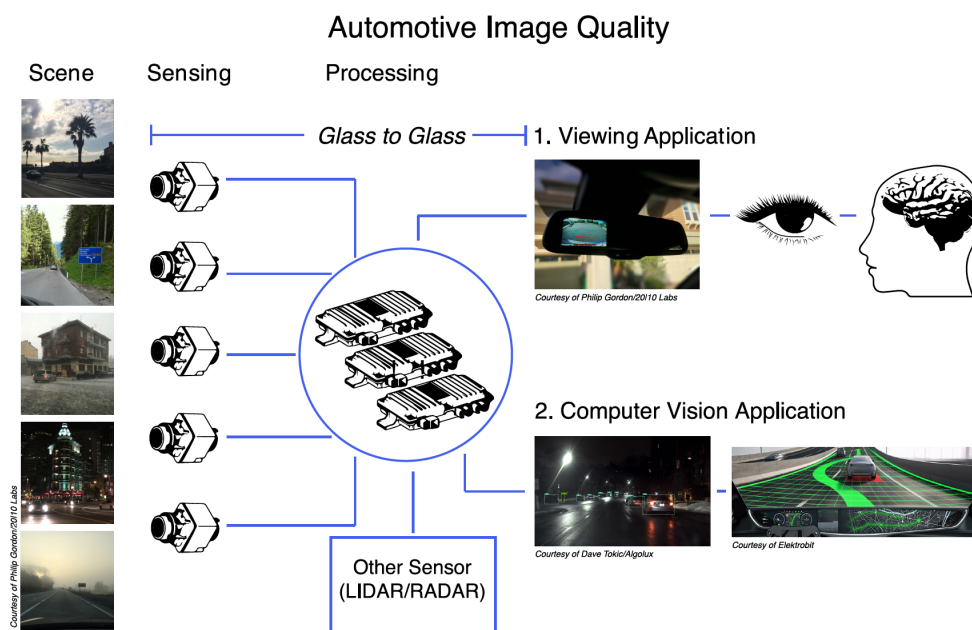


Figure 1 Architecture of multi-camera automotive system

For viewing-based camera systems (pathway 1 in Figure 1), the output image has to fulfill the pleasantness aspect of image quality, which is related to the visual appeal of the image and is a key aspect of the quality of experience (QoE) or level of satisfaction of the user. In such systems, however, the usefulness aspect of IQ, related to the amount of useful information the visual image conveys (e.g., visible detail in shadow areas), is also vital. Balancing pleasantness and usefulness is a challenge in the IQ tuning of viewing-based camera systems, since the two do not always correlate.

For computer vision-based systems (pathway 2 in Figure 1), the individual products' configuration of the hardware components [lens, image sensor, image signal processor (ISP), etc.], their parameterization, as well as the complete system IQ tuning, all have to prioritize usefulness. Here, it is important to note that biological vision and computer systems do not necessarily interpret useful information in the same manner.

Both viewing and computer vision camera systems are integral to many infotainment, driver assistance, and automated driving functions. For some of these applications, images are the primary input for the human driver or computer vision system to recognize and react to its environment. Therefore, it is extremely important that meaningful KPIs are developed to quantify and describe the performance and limits of a camera system used in such applications.

The Society of Automobile Engineers (SAE) has defined five levels of driver automation in SAE J3016 [9] with increasing levels of driving function assigned to the system, see Figure 2. These automated vehicles will use suites of sensors based on different technologies, of which camera systems are integral parts. As the automated driving systems increasingly take more responsibility for human lives, it becomes urgent to develop standard metrics to measure the performance and limits of image quality of these camera systems.

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)
Human driver monitors the driving environment						
0	No Automation	the full-time performance by the <i>human driver</i> of all aspects of the <i>dynamic driving task</i> , even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the <i>driving mode</i> -specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the <i>driving mode</i> -specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the <i>human driver</i> perform all remaining aspects of the <i>dynamic driving task</i>	System	Human driver	Human driver	Some driving modes
Automated driving system ("system") monitors the driving environment						
3	Conditional Automation	the <i>driving mode</i> -specific performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> with the expectation that the <i>human driver</i> will respond appropriately to a <i>request to intervene</i>	System	System	Human driver	Some driving modes
4	High Automation	the <i>driving mode</i> -specific performance by an automated driving system of all aspects of the <i>dynamic driving task</i> , even if a <i>human driver</i> does not respond appropriately to a <i>request to intervene</i>	System	System	System	Some driving modes
5	Full Automation	the full-time performance by an <i>automated driving system</i> of all aspects of the <i>dynamic driving task</i> under all roadway and environmental conditions that can be managed by a <i>human driver</i>	System	System	System	All driving modes

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Figure 2 SAE autonomous driving levels as defined in the standard SAE J3016 [9]

A. Goals of this white paper

This white paper is the first publication of the IEEE P2020 Working Group on Automotive Imaging. A lesson learned from the sibling group IEEE P1858 Camera Phone Image Quality (CPIQ) is that an ambitious standards development effort in a rapidly changing technological field with so many different stakeholders can take many years to be approved and published.

After our initial face-to-face meetings, it became clear that simply defining the relevant questions and listing the open challenges would already be a useful achievement worth publishing. Typically, this information would be published together with the actual IEEE P2020 standard, and would occur only after the new image quality metrics

and new relevant KPIs have been defined, which may still take some time. Therefore, independent of the IEEE P2020 standard publication stage, we decided to aim for intermediate publications to quickly communicate the progress that the working group has made toward understanding automotive image quality. This white paper is the first of these publications.

Consequently, the goals of this white paper are as follows:

- 1) **Raise awareness that image quality for automotive application is not well-defined**, critical metrics for specification are missing, leading to repeated work efforts towards that matter. This white paper has two sections that raise the awareness about missing image quality standards. Section 1-C gives the motivation to start the IEEE P2020 effort in the first place. This includes information from the project authorization request (PAR). Section 2 introduces several problem statements; each is a summary of findings by each subgroup. In Section 3, a gap analysis of the existing image quality standards is provided. This is a list of KPIs that are relevant for automotive image quality with a reference to existing standards, and also provides an indication of the KPIs that do not have a standard (i.e., gaps in the standards landscape). Further, the existing standards are often difficult or impossible to apply in automotive applications, or they lack certain key features (e.g., in ISO 12233 [7], the evaluation of HDR is not covered). The presented list contains commentary on what elements we consider missing or incomplete.
- 2) **Raise awareness that the IEEE P2020 working group is trying to remedy** these deficiencies to the best extent as possible. It is time to develop a common language that customers and suppliers can use to efficiently describe automotive image quality requirements. This publication attempts to raise awareness that such an effort is under way.
- 3) **Connect with other people already working on similar challenges**. Because this field of technology is advancing rapidly, and due to the enormous resources pouring into the development of new camera systems for the automotive market, there are many people and organizations worldwide that are already working on many individual aspects of automotive image quality. What applies to the goal of the standard applies to the development of the standard itself—avoid duplicated efforts by connecting people working in the field and raise synergies. This white paper points out the problematic state of automotive image quality, and thus an important goal of this publication is to link together those who are already working on solutions to fill the gaps.
- 4) **Attract more people** to help with the IEEE P2020 effort. This white paper is also a call to attract more people and forge collaborations to help shape the future standards of automotive image quality.

B. Structure of this white paper

The rest of this section explains the motivation for the IEEE P2020 working group in more detail, the long-term objectives of IEEE P2020 as well as the current structure of the working group with its different subgroups. The actual content follows in the next two main sections:

- A problem statement by each subgroup is given in Section 2.
- A gap analysis is given in Section 3.

Section 2 describes the activity of each subgroup and formulates the challenges and missing standards in that area into a problem statement. Currently, three of the later mentioned six subgroups are active and work to define new quality metrics—subgroup 1: LED-Flicker, subgroup 2: IQ for viewing, and subgroup 3: IQ for computer vision.

The problem statements are generalized overviews of the main thrust of the work pursued by each subgroup. A more detailed list of missing metrics and lacking standards is further given in the gap analysis in Section 3, where Table 1 lists KPIs identified as important for automotive image quality. Where applicable, an existing standard is