Towards Semantic Modeling of Camera from Image Quality Testing Perspective: Valeo Vision Systems Case

Muhammad Yahya[1], Aedán Breathnach[1], Faisal Khan[1], Iman Abaspur[1] and Rajkumar Ranganathan[1]

[1]*Valeo Vision Systems, Dunmore, Tuam, Galway, Ireland*

Abstract

Advanced Driving Assistance Systems (ADAS) have significantly enhanced the modern driving experience by integrating state-of-the-art technology to bolster vehicle safety and driver comfort. Cameras, serving as the eyes of these systems, are pivotal in capturing real-time visual data. This data is processed and analyzed to make instantaneous decisions, such as object detection and lane departure warnings. The manufacturing of the camera has to pass certain tests to qualify the production. During the production, it generated a huge amount of data which is stored in different storage places. This, however take huge efforts and time for image quality team to digest such scattered data. To solve this issue of data integrity, we propose Camera Ontology (CamOnt) with the scope to represent the camera testing domain knowledge. The ontology is built using the knowledge gathered from the domain experts and ISO12233 document, and is evaluated with the catalogue of SPARQL queries provided.

Keywords

ADAS, Ontology modeling, Image Quality Measurement,

1. Introduction

Advanced Driving Assistance Systems (ADAS) have revolutionized the modern driving experience by integrating cutting-edge technology to improve vehicle safety and driver comfort [1]. By offering features such as adaptive cruise control, lane departure warnings, automatic emergency braking, and parking assistance, ADAS reduces the likelihood of accidents and alleviates driver fatigue and stress [2]. As a result, drivers enjoy a more relaxed and confident driving experience. Moreover, the widespread adoption of ADAS has the potential to significantly reduce traffic accidents and fatalities, making roads safer for everyone [3]. The integration of these systems is gradually shifting the responsibility of driving from humans to machines, paving the way for the future of autonomous vehicles and transforming the way society perceives and interacts with transportation.

Cameras play a pivotal role in the functionality and efficiency of Advanced Driving Assistance

SemIIM'23: 2nd International Workshop on Semantic Industrial Information Modelling, 7th November 2023, Athens, Greece, co-located with 22nd International Semantic Web Conference (ISWC 2023)

muhammad.yahya@valeo.com (M. Yahya); aedán.breathnach@valeo.com (A. Breathnach); faisal.khan@valeo.com (F. Khan); iman.abaspur@valeo.com (I. Abaspur); rajkumar.ranganathan@valeo.com (R. Ranganathan)

Systems (ADAS) [4]. Serving as the eyes of the system, cameras capture real-time visual data, which is then processed and analyzed to make split-second decisions, such as object detection, lane departure warnings, and pedestrian alerts. The precision and reliability of these cameras directly influence the system's ability to prevent potential accidents and ensure driver safety. However, If an ADAS camera fails, the system may not detect obstacles or misinterpret visual data, leading to compromised safety features and an increased risk of accidents [5, 6]. Causes of camera failure can range from physical obstructions like dirt or debris on the lens, software glitches, and malfunctioning hardware components, to adverse environmental conditions such as extreme temperatures. Ensuring the consistent performance and reliability of ADAS cameras is thus paramount for the overall safety and effectiveness of the system.

Valeo[1], an Original Equipment Manufacturer (OEM) and a global automotive supplier is at the forefront of developing advanced vision systems that play a crucial role in the realm of ADAS. Their state-of-the-art cameras are designed to enhance vehicle safety by providing a comprehensive view of the vehicle's surroundings, enabling features such as lane departure warnings, traffic sign recognition, and pedestrian detection. Valeo's vision systems leverage sophisticated image processing algorithms and high-resolution sensors to ensure accurate real-time data interpretation, even in challenging lighting or weather conditions. As ADAS technologies continue to evolve towards fully autonomous driving, Valeo's commitment to innovation and quality ensures that its cameras remain an integral component in driving safety advancements, helping to reduce accidents and save lives on the road.

Each camera undergoes rigorous testing to meet specified standards in the Valeo production lines. During these tests a huge amount of data is produced, that is then stored across various storage locations. The Image Quality (IQ) team is responsible for evaluating this scattered data to ensure that testing criteria are met. The challenge, however, arises from the dispersion of data across multiple locations, resulting in the IQ team spending an extended duration on this task.

To address this issue ontology emerged as a significant tool to integrate the data [7]. Ontologies[2] appeared as a significant tool to represent the domain knowledge of the manufacturing domain to support data integration and interoperability [10, 11].

In this work, we are proposing Camera Ontology (CamOnt) to integrate the data residing in different places in Valeo vision system. The CamOnt is built with the knowledge gathered from the Valeo experts with the scope defined to help the image quality team access the data integrated via a uniform model. At present, the ontology is evaluated with the experts-defined query catalogue.

2. Related Work

In the evolving landscape of semantic web technologies, ontologies have emerged as pivotal techniques for representing domain-specific knowledge [12, 13, 14]. The domain of camera

[1]https://www.valeo.com/en/catalogue/cda/surround-view-camera-solutions/

[2]Gruber et al. 1993 [8], define an *ontology as the formal, explicit specification of a shared conceptualization.* The basic elements of an ontology are a concept and the relation between it, and its axioms. When the instances of concepts are populated into the developed ontology it becomes a knowledge base also known as knowledge graph [9]. There are two key elements in Ontology: terminological components (Tbox) and assertional components (Abox) that specify the concepts and their instances, respectively.

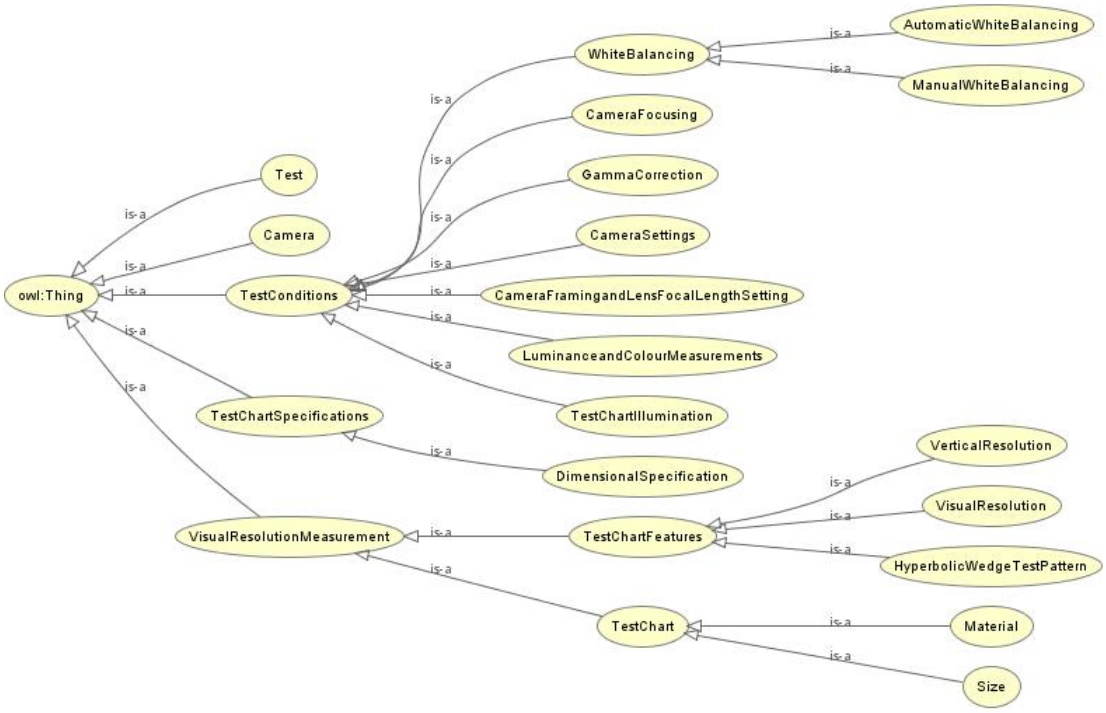

Figure 1: Class hierarchy of the Camera testing ontology

technology and testing is no exception, with several attempts made to formalize and structure the vast array of concepts and relationships inherent to it.

Wei et. al explored sentiment analysis within the context of digital camera reviews [15]. They constructed a Sentiment Ontology Tree (SOT) specifically for digital cameras, which contained nodes representing various attributes of the camera and their associated sentiments. This work provides a unique perspective on camera ontology, emphasizing the sentiment aspect of camera attributes rather than just the technical specifications. In the visual domain, the Spatio-Temporal Visual Ontology was introduced [16]. While not directly related to cameras, it offers insights into the semantic representation of visual data, such as images produced by cameras. A notable contribution in the broader realm of product families comes from Nanda et al. [17]. They showcased the practicality of the Product Family Ontology Development Methodology (PFODM) by constructing an ontology for a family of one-time-use cameras.

There are existing ontologies like the aforementioned that touch on cameras, but they don't specifically address the complexity of camera testing for automotive use. However, camera technology in the automotive sector is crucial for enhancing safety. Our work fills this gap, focusing on this niche yet vital area. The rapid evolution of camera tech highlights the need for such a specialized ontology, especially since current literature doesn't adequately cover this domain.

3. Ontology Development Methodology

We now discuss the ontology development process. We have adopted the ontology development process from [18]. In the pursuit of a semantic model for camera image quality testing, the Valeo Vision Systems case study emphasize the significance of a structured ontology development approach. The initial phase involves defining the functional and non-functional requirements for an ontology tailored to the complexity of camera image quality. Collaborating with domain experts in line with ISO12233 document, specific use-cases related to the Image quality is described. This is strengthen by a thorough examination of ISO12233 standard document, and datasets, laying the groundwork for the ontology's purpose and scope.

The next phase is the formalization of concepts. By scrutinizing existing ontologies, relevant terminologies are searched, ensuring alignment with the camera domain. This meticulous formalization is characterized by establishing relationships between concepts. For instance, a concept like `ImageSensor` might be linked to `ImageProcessingAlgorithm` through specific properties. Leveraging tools such as Protégé, these formalized concepts are seamlessly translated into RDF/OWL formats. After the development of the ontology, the next step is its evaluation. In this preliminary work, we have evaluated our ontology based on a competency questions.

4. Ontology Overview

The section presents an overview of the CamOnt ontology. The ontology focuses on the domain of camera testing and visual resolution measurements (see Figure 1 for class hierarchy). The ontology encapsulates various aspects of camera testing, from the settings and conditions under which cameras are tested to the specific features of test charts used in visual resolution measurements.

The key classes in the ontology include `Camera`, which represents the primary entity being tested, and Test, which captures the various tests a camera might undergo. The ontology also delves into the nuances of test conditions, such as white balancing (`AutomaticWhiteBalancing` and `ManualWhiteBalancing`), gamma correction (`GammaCorrection`), and camera focusing (CameraFocusing). Test charts, essential tools in camera testing, are represented with classes like `TestChart`, `DimensionalSpecification`, and `HyperbolicWedgeTestPattern`. Table 1

Table 1
Classes and their definitions in the Ontology

Class	Definition
Camera	The primary entity being tested, representing any camera device.
Test	Captures the various evaluations or procedures a camera may undergo.
AutomaticWhiteBalancing	Represents the automatic method of adjusting the colour balance in images taken by the camera.
ManualWhiteBalancing	Denotes the manual method of adjusting the colour balance in images.
GammaCorrection	Refers to the adjustment of luminance or colour values in the image.
CameraFocusing	Represents the techniques or methods used by the camera to focus on subjects.
TestChart	A tool or pattern used in camera testing to evaluate various parameters.
DimensionalSpecification	Specifies the dimensions or size-related attributes of a test chart.
HyperbolicWedgeTestPattern	A specific pattern on a test chart used for certain evaluations.

Table 2
Object properties with their respective domains and ranges in the camera testing ontology.

Object Property	Domain	Range
hasTest	Camera	Test
hasTestConditions	Test	TestConditions
hasChartSpecifications	Test	TestChartSpecifications
hasResolutionMeasurements	Test	ResolutionMeasurements
usesWhiteBalancing	Camera	WhiteBalancing
employsTestChart	Test	TestChart
hasCameraSetting	Test	CameraSettings
measuresWithPattern	VisualResolutionMeasurement	HyperbolicWedgeTestPattern
hasMaterialType	TestChart	Material
adjustsGammaWith	Camera	GammaCorrection

shows some of the classes with their definitions.

The ontology defines several object properties to capture the relationships between these classes. For instance, *hasTestConditions* can link a Test to its specific conditions, while *usesWhiteBalancing* might specify the type of white balancing a camera employs. Table 2 shows some of the object properties with their domain and range.

To exemplify the domain knowledge, consider axiom 1 which states that there exists some cameras that use the automatic white-balancing method. Axiom 2 represents that there exist some tests that employ the Hyperbolic Wedge Test Pattern in their test charts. Moreover, axiom 3 states that there exist some cameras that have a specific lens setting of type Camera Framing and Lens Focal Length Setting and also use a focusing method of type Camera Focusing.

1. Camera ⊓ ∃usesWhiteBalancing.AutomaticWhiteBalancing
2. Test ⊓ ∃employsTestChart.HyperbolicWedgeTestPattern
3. Camera⊓∃hasLensSetting.CameraFramingandLensFocalLengthSetting⊓∃usesFocusingMethod.CameraFocusing

5. Evaluation

According to Gomez-Perez et al. 1995, ontology evaluation is a technical judgment of the ontology in relation to a frame of reference [19]. This frame of reference can encompass requirement specifications, competency questions, and its real-world applications. A crucial aspect of ontology evaluation is the formulation of competency questions from the user's perspective to ascertain if the ontology meets its intended purpose. Hammar et. al 2010 proposed the creation of usage examples in natural language to highlight the significance of the ontology's concepts [20]. Commonly termed competency questions, these user-centric queries are instrumental in gauging the ontology's scope. Essentially, they represent the questions

Table 3: Competency questions and their SPARQL representation with patterns. CE: Class Expression, OPE: object property, DP: datatype property

Competency Question	Pattern	SPARQL Query
Q1. Which cameras use Automatic White Balancing?	[CE1][OP1][CE2]	select ?camera where { ?camera cam:usesWhite-Balancing cam:AutomaticWhiteBalancing. }
Q2. What are the test charts used in a specific test?	[CE1][OP1][CE2]	select ?testChart where { ?test cam:employsTestChart ?testChart. }
Q3. Which cameras have a specific lens setting?	[CE1][OP1][CE2]	select ?camera where {?camera cam:hasLensSetting cam:CameraFramingandLensFocalLengthSetting. }
Q4. What are the different gamma corrections used in camera tests?	[CE1][OP1][CE2]	select ?gammaCorrection where { ?test cam:employsGammaCorrection ?gammaCorrection. }
Q5. Which cameras use a specific focusing method?	[CE1][OP1][CE2]	select ?camera where { ?camera cam:usesFocusingMethod cam:CameraFocusing. }

stakeholders aim to answer using the ontology and its linked knowledge base. Hence, designing a comprehensive set of competency questions that encapsulate most real-world scenarios is imperative. These questions necessitate thorough scrutiny to eliminate any that are irrelevant.

5.1. Competency Questions: Valeo Use-case

In the context of CamOnt, the competency questions were sourced from Camera IQ domain experts, eliminating the need for an in-depth analysis of their effectiveness. It is worth noting that experts who provide domain knowledge are different from those gave SPARQL queries. These questions are tabulated in Table 3. The table's first column presents the competency questions in natural language, the second column delineates the triple pattern addressed by each question, and the final column showcases the corresponding SPARQL query designed to extract the requisite knowledge. Furthermore, we incorporated instances of camera data to validate the capability of the CamOnt to represent it. The SPARQL queries are tailored to examine the camera and their test results. Each test is conducted with specific parameters like lens setting, white balancing method, gamma correction, and test chart used. These parameters are interconnected to the test via specific relations. For instance, query 1 reveals that an XYZ[3] camera utilized an automatic white balancing, query 2 returns a test chart of a hyperbolic wedge test pattern and query 4 with a gamma correction of 2 is used in a particular test.

6. Conclusion and Future work

In this paper, we have developed and presented the CamOnt ontology, a semantic model tailored for the domain of camera testing and visual resolution measurements. Our ontology stands as a testament to the interplay between camera technology and semantic modeling, offering a structured approach to understanding and analyzing camera tests. The ontology is developed with the knowledge acquired from ISO12233 documents and domain experts. Furthermore, the competency questions, curated with insights from domain experts, underscore the real-world relevance and robustness of CamOnt. The catalogue of SPARQL queries, specifically designed for CamOnt, showcases its ability to extract detailed insights and highlights its potential as a valuable tool for Valeo end users. In future, we will incorporate more domain knowledge of cameras other than testing. Its harmonization with DOLCE or BFO will be carried out will be carried out in the future.

References

[1] M. A. Farooq, P. Corcoran, C. Rotariu, W. Shariff, Object detection in thermal spectrum for advanced driver-assistance systems (adas), IEEE Access 9 (2021) 156465–156481.

[2] W.-Y. Chung, T.-W. Chong, B.-G. Lee, Methods to detect and reduce driver stress: a review, International journal of automotive technology 20 (2019) 1051–1063.

[3] S. Barakoti, Enhancing driving safety using artificial intelligence technology (2023).

[3] Used dummy data instead of the actual values due to Valeo's data policy. The data can not be shared in any form outside the organization. Due to the policy, we are unable to share the figures of the real queries.

[4] J. S. Murthy, G. Siddesh, W.-C. Lai, B. Parameshachari, S. N. Patil, K. Hemalatha, Objectdetect: A real-time object detection framework for advanced driver assistant systems using yolov5, Wireless Communications and Mobile Computing 2022 (2022).
[5] A. Ebrahimi, E. Akbari, Design and implementation of an affordable reversing camera system with object detection and obd-2 integration for commercial vehicles, 2023.
[6] A. Wahid, M. Yahya, J. G. Breslin, M. A. Intizar, Self-attention transformer-based architecture for remaining useful life estimation of complex machines, Procedia Computer Science 217 (2023) 456–464.
[7] B. Zhou, Z. Tan, Z. Zheng, D. Zhou, Y. He, Y. Zhu, M. Yahya, T.-K. Tran, D. Stepanova, M. H. Gad-Elrab, et al., Neuro-Symbolic AI at Bosch: Data Foundation, Insights, and Deployment, Technical Report, 2022.
[8] T. R. Gruber, A translation approach to portable ontology specifications, Knowledge acquisition 5 (1993) 199–220.
[9] M. Yahya, J. G. Breslin, M. I. Ali, Semantic web and knowledge graphs for industry 4.0, Applied Sciences 11 (2021) 5110.
[10] M. Yahya, B. Zhou, Z. Zheng, D. Zhou, J. G. Breslin, M. I. Ali, E. Kharlamov, Towards generalized welding ontology in line with iso and knowledge graph construction, in: European Semantic Web Conference, Springer, 2022, pp. 83–88.
[11] M. Yahya, A. Ali, Q. Mehmood, L. Yang, J. G. Breslin, M. I. Ali, A benchmark dataset with knowledge graph generation for industry 4.0 production lines, Semantic Web (????) 1–19.
[12] D. Rincon-Yanez, M. H. Gad-Elrab, D. Stepanova, K. T. Tran, C. C. Xuan, B. Zhou, E. Karlamov, Addressing the scalability bottleneck of semantic technologies at bosch, arXiv preprint arXiv:2309.10550 (2023).
[13] Z. Zheng, B. Zhou, A. Soylu, E. Kharlamov, Towards a visualisation ontology for data analysis in industrial applications (2022).
[14] A. Iqbal, A. Shahid, M. Roman, M. T. Afzal, M. Yahya, Exploiting contextual word embedding for identification of important citations: Incorporating section-wise citation counts and metadata features, IEEE Access 11 (2023) 114044–114060. doi:10.1109/ACCESS.2023.3320038.
[15] W. Wei, J. A. Gulla, Sentiment learning on product reviews via sentiment ontology tree, in: Proceedings of the 48th Annual Meeting of the Association for Computational Linguistics, 2010, pp. 404–413.
[16] J. I. Olszewska, Spatio-temporal visual ontology, in: BMVA/EACL EPSRC Workshop on Vision and Language (VL'11), 2011.
[17] J. Nanda, T. W. Simpson, S. R. Kumara, S. B. Shooter, A methodology for product family ontology development using formal concept analysis and web ontology language (2006).
[18] M. Yahya, B. Zhou, J. G. Breslin, M. I. Ali, E. Kharlamov, Semantic modeling, development and evaluation for the resistance spot welding industry, IEEE Access (2023).
[19] A. Gómez-Pérez, N. Juristo, J. Pazos, Evaluation and assessment of knowledge sharing technology, Towards very large knowledge bases (1995) 289–296.
[20] K. Hammar, K. Sandkuhl, The state of ontology pattern research: a systematic review of iswc, eswc and aswc 2005–2009, in: The Workshop On Ontology Patterns (WOP 2010) At The 9th International Semantic Web Conference (ISWC 2010), 2010, pp. 5–17.