Vehicular Visible Light Communication Channel Models: A systematic review

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Aims and Background

Abstract:

This study evaluates the latest advancements of **Vehicular Visible Light Communication (V-VLC) channel models** with a focus on **the photometric aspects.** V-VLC is an alternative communication method to radio-frequency (RF) systems for Intelligent Transportation Systems.

V-VLC Topology:

The V-VLC system's architecture consists of three components: transmitter, optical channel, and receiver, encompassing application (APP), medium access control (MAC), and physical (PHY) layers. This paper focuses on the **Free Space Optical Channel** in the PHY layer.

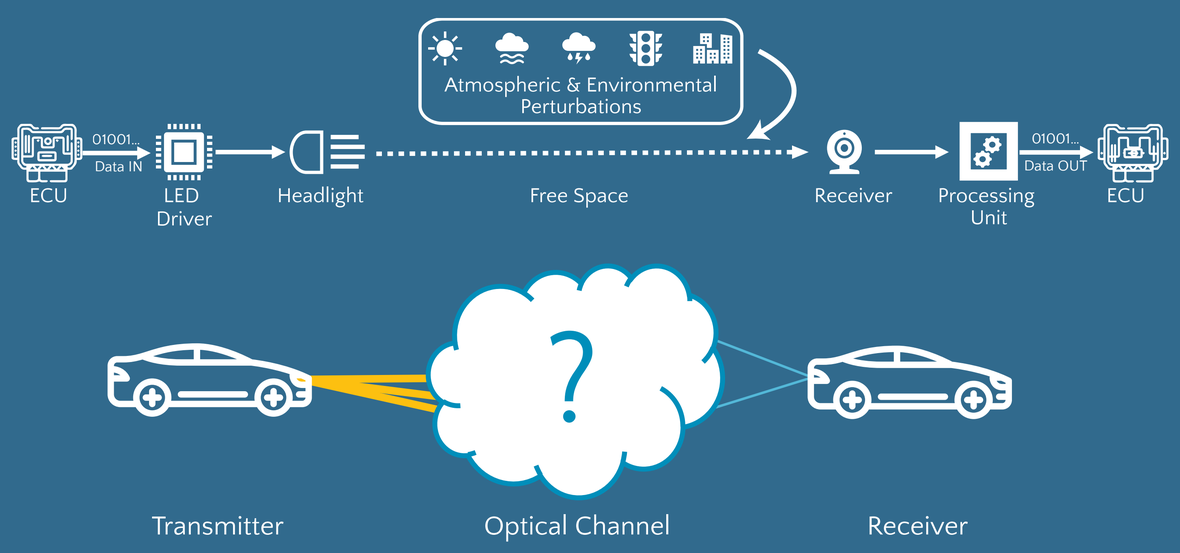


Figure 1: Schematic overview of the V-VLC working principle. The cloud in between transmitting and receiving vehicle represents the optical channel model requiring more attention.

Materials and Methods

A systematic approach to the gathering of relevant source is employed. A two-stage selection process is applied following predefined inclusion and exclusion criteria. Review and research articles are sought after in different steps as both serve a different purpose.

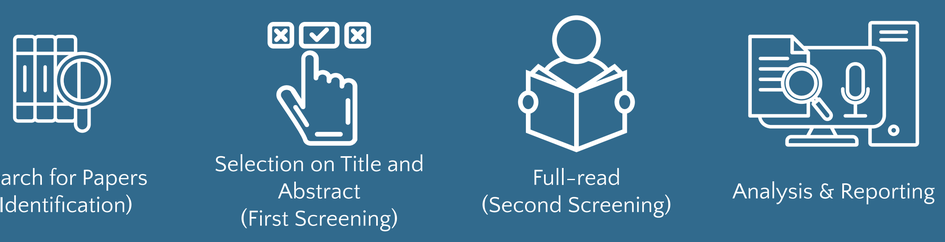


Figure 2: Schematic representation of the search and screening procedure.

Review Articles:

Databases:
IEEE, Scopus, Web Of Science
Keywords:
Vehicular, Visible Light Communication, Review

Number of Articles:
18 Found, 16 Retrieved, 12 Selected, 8 Retained
Analysis:
After full-read, these review articles were used to synthesise existing research and track the evolution of ideas.

Research Articles:

Databases:
IEEE, Scopus, Web Of Science
Keywords:
Vehicular, Visible Light Communication, Channel Model, Vehicle to Vehicle, Luminous Intensity Distribution, LED
Number of Articles:
93 Found, 67 Retrieved, 31 Selected, 16 Retained
Analysis:
After full-read, these research papers are used to highlight the latest advancements in V-VLC channel modelling.

Results

Radiation Pattern

Recent studies use familiar light source models, mainly **Lambertian** and **Gaussian**, though lacking accuracy for low beam headlamps. Realism improves with **measured patterns** or **fitted models**.

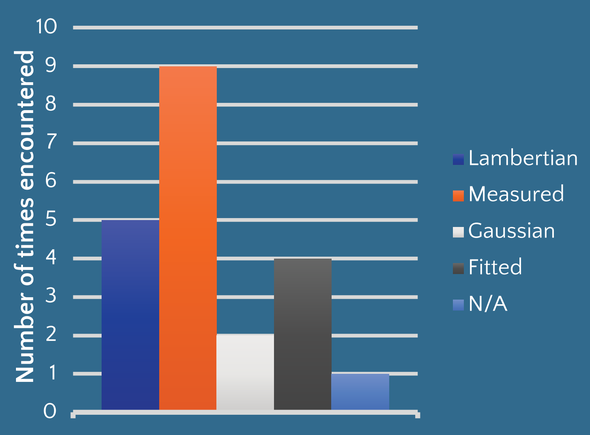


Figure 3: Summary of the used light source model

Modelling Approach

Recent literature uses ray tracing, analytical expressions, measurement campaigns, machine learning, and Monte Carlo simulations for channel modelling. Combining methods offers a comprehensive approach.

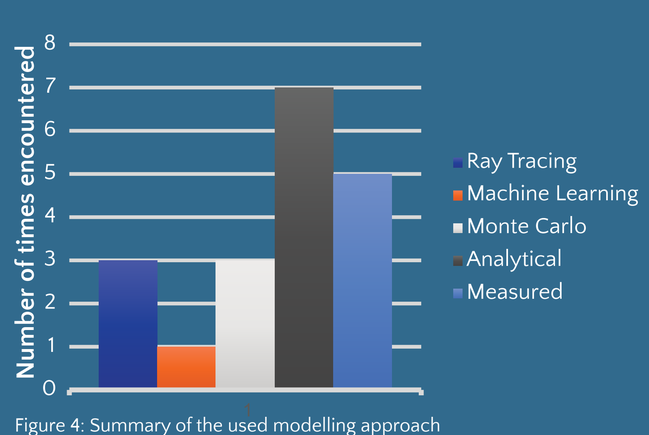


Figure 4: Summary of the used modelling approach

Influencing Factors

Traffic density affects inter-vehicle distance and NLOS paths, impacting signal quality. Geometrical factors, which vary with road conditions, influence emission and arrival angles dynamically. Parasitic sources add noise to the system. All influencing factors are interconnected rendering statistical modelling desirable.

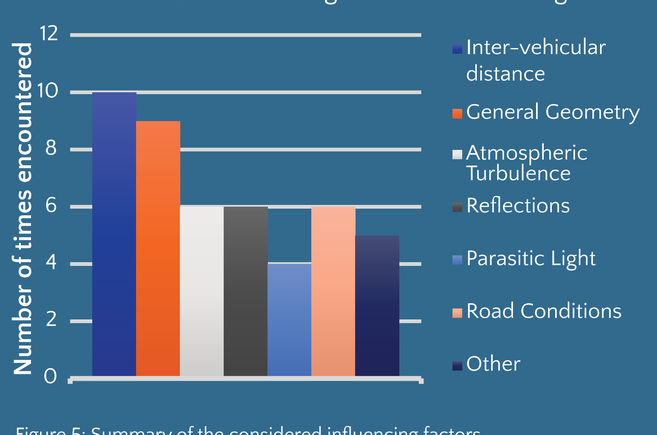


Figure 5: Summary of the considered influencing factors

Discussion

Analytical models generally simplify transmitter characteristics through **generalised piece-wise Lambertian Luminous Intensity Distributions.** The asymmetrical patterns of vehicular headlights are needed for realistic modelling.

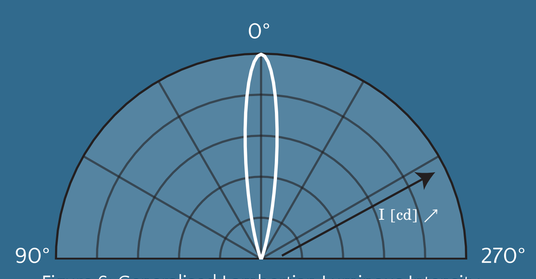


Figure 6: Generalised Lambertian Luminous Intensity Distribution with a Full Width at Half Maximum of ≈8°.

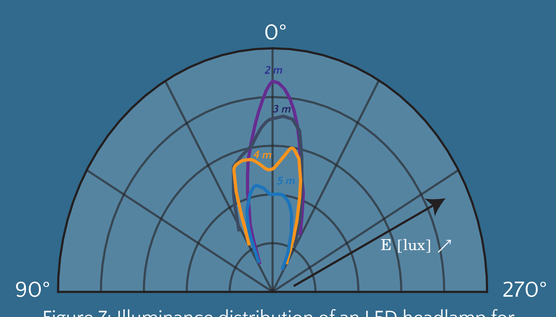


Figure 7: Illuminance distribution of an LED headlamp for different measurement distances [1].

Figure 8: HELLA 84 matrix LED Vehicle Headlight [2].

Vehicles increasingly adopt diverse light sources like **matrix LED or laser headlights**. It would be valuable to explore their usage in V-VLC systems more often.

NLOS links are increasingly considered. Improving current observatiosn can be obtained through **spectral Bidirectional Scattering Distribution Function** analysis .

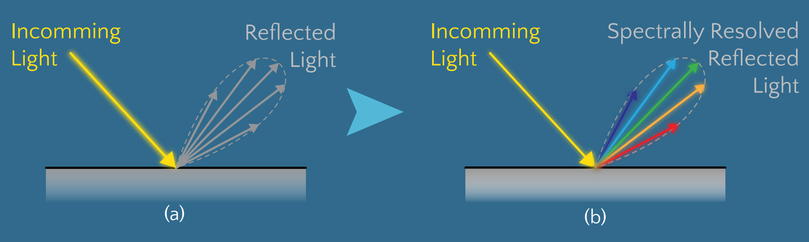
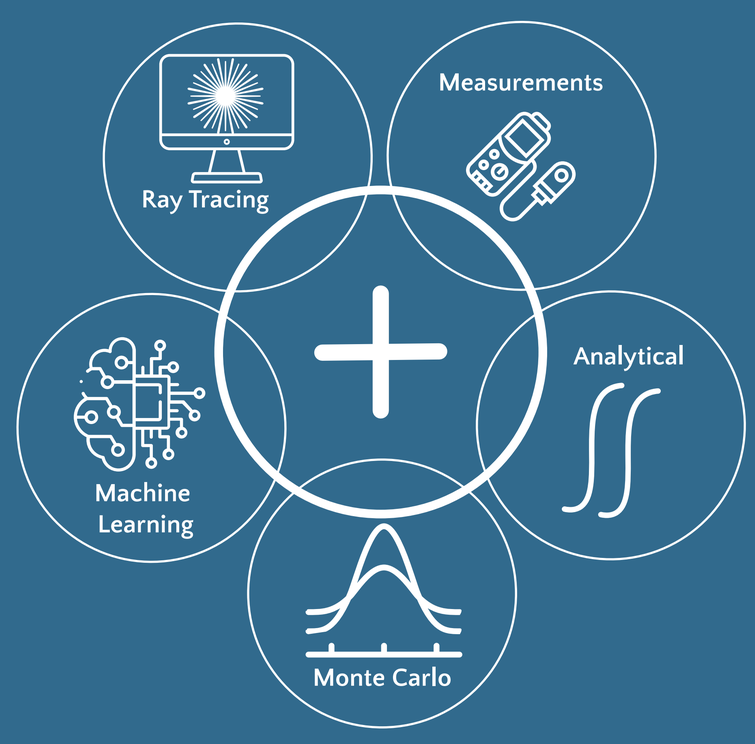


Figure 9: Schematic representation of a specular reflection considering: (a) each wavelength to be reflected in the same manner and (b) a spectrally resolved light reflection.



Combining modelling approaches, should enhance channel models. Current literature lacks comprehensive combined modelling approaches, indicating a need for further research in this area.

Conclusion

Review Papers	Research Articles	State of the Art:
n = 8	n = 16	- 4 Radiation Pattern Representations
2013 - 2023	2021 - 2024	- 5 Modelling Approaches
Comprehensive Overview	Latest Findings	- >7 Influencing Factors Analysed

Future Prospects:

1) Photometric headlight characterisation
2) Spectrally dependent reflections (NLOS link)
3) Combination of modelling approaches

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Sources:
[1] A. Rammohan and C. RameshKumar, "Investigation on light intensity and temperature distribution of Automotive's Halogen and LED headlight," 2017 International conference on Microelectronic Devices, Circuits and Systems (ICMDCS), Vellore, India, 2017, pp. 1-6, doi: 10.1109/ICMDCS.2017.8211592.
[2] source: PR Newswire, Mercedes Multibeam LED headlamps - in a class of their own, June 22nd 2016, *https://www.prnewswire.com/news-releases/mercedes-multibeam-led-headlamps--in-a-class-of-their-own-300288628.html,* Last visited on 15/03/2024
[3] Pictograms from the https://thenounproject.com/