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A Comprehensive Review of Li-Fi Systems for Text and Data Transmission

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مراجعة شاملة لأنظمة (Li-Fi) لإرسال النصوص والبيانات

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Abstract:
Text transmission via Li-Fi is shown to be feasible across multiple prototype systems. One study describes a low-cost setup that sends text using an LED, an ATmega16L, an operational amplifier, and a photodiode with binary on/off encoding,reporting “top notch” speed, efficiency, and security. Two other studies employing LED bulbs and photodiode receivers use light intensity modulation to send both text and images at speeds of 10 Mbps (with a goal of 100 Mbps), while another system using high-power LED arrays reports rates up to 500 Mbit/s. Most implementations rely on simple LED sources paired with photodiodes (often supported by microcontrollers such as Arduino, ATmega16L, or PIC) and achieve high security, though limitations in range and a requirement for line-of-sight are noted. Several studies explicitly state that text messaging can be managed by encoding techniques such as binary mapping (including Morse code) or by varying LED current intensity. These results support sending text using Li-Fi technology when systems use off-the-shelf components and standard protocols, achieving competitive and sometimes superior performance compared with traditional wireless communication.

Keywords: Li-Fi, VLC system, Photodiode, Light modulation technique.

الملخص:
لقد ثبت من خلال عدة دراسات امكانية نقل البيانات بواسطة الضوء المرئي أو ما يسمى بتقنية (Li-Fi) هذه التقنية يمكن تصميمها بواسطة دوائر الكترونية بسيطة نوردها تباعا في هذه الدراسة حيث تصف إحدى هذه الدراسات نموذج لدائرة الكترونية منخفضة التكلفة ترسل نصًا باستخدام الثنائي الضوئي (LED) و متحكم دقيق (ATmega16L) و مكبر عملياتي(Operation Amplifier) وثنائي تأثيرا لضوء (Photodiode) كمستقبل لإشارة رقمية مشفرة على هيئة (Off / On) حيث أثبتت هذه البنية البسيطة سرعة وكفاءة وأمان من الدرجة الأولى و تفيد دراستان أخريان أحداهما تستخدم مصابيح LED وأجهزة للتحكم في شدة استضاءة الثنائيات الضوئية لإرسال النصوص والصور بسرعات تصل إلى 10 ميجابت في الثانية (وإمكانية الوصول إلى 100 ميجابت في الثانية) وآخرى تستخدم ثنائي ذو قدرة عالية أو مصفوفة ثنائيات للوصول إلى معدل نقل بيانات 500 ميجابت في الثانية .تعتمد معظم هذه التطبيقات على مرسلة ضوئية عبارة عن ثنائي ضوئي (LED) غالبًا ما تدعمها وحدات التحكم الدقيقة مثل (Arduino)، (ATmega16L) أو (PIC)

وتحقق أمانًا عاليًا على الرغم من محدودية نطاق الارسال المقيدة بمسافة الإضاءة لذلك يمكن الاستفادة من هذه التقنية في الأماكن الداخلية (الغرف ة الصالات و الأماكن المحجوزة بجدر). تشير العديد من الدراسات صراحةً إلى أنه يمكن إدارة الرسائل النصية من خلال تقنيات الترميز مثل التضمين الثنائي (بما في ذلك شفرة مورس) أو عن طريق تغيير شدة استضاءة الـ LED، تخبر هذه الدراسات ايضا بشكل صريح إمكانية ارسال البيانات بواسطة الضوء و عن طريق برتوكولات نقل البيانات بطريقة تنافسية مقارنة مع الطرق التقليدية لنقل البيانات لاسلكياً.

الكلمات المفتاحية: تقنية لاي فاي، الاتصال بواسطة الضوء المرئي، الثنائي الضوئي، تقنية التضمين الضوئي.

Introduction:

In the ever-shifting world of wireless communication, Light Fidelity (Li-Fi) is a revolutionary technology that utilizes the visible light spectrum to transfer data at unprecedented speeds. Unlike Wi-Fi and other RF systems, Li-Fi uses light-emitting diodes (LEDs) to encode and transmit information, creating a new paradigm for fast, safe, and interference-free communication. The fundamental architecture of Li-Fi is remarkably simple: a transmitter modulates the intensity of light from an LED source, while a photodiode receiver decodes the fluctuations into digital data. This simplicity translates into reduced hardware complexity and significantly lower implementation costs, making Li-Fi an attractive solution for both industrial and consumer applications.

This paper aims to synthesize the collective insights from these studies, highlighting the technological potential of Li-Fi as a next-generation communication medium. By examining its structural elegance, cost-effectiveness, and superior data handling capabilities, we seek to establish a comprehensive understanding of Li-Fi’s role in shaping the future of wireless communication.

Paper search:

To answer the research question of 'Send data using Li-Fi technology', we searched for academic papers in the Semantic Scholar corpus. Out of the 50 papers that were most relevant to the query, we retrieved the most relevant ones.

Screening:

Sources that met these criteria were screened by us:

- **Technology Focus**: Does the study investigate Li-Fi (Light Fidelity) or visible light communication (VLC) systems for text or data transmission?
- **Study Design and Validation**: Is the study an experimental study, pilot study, case study, or technical evaluation with actual testing or validation of text transmission capabilities (not purely theoretical or simulation-only)?
- **Performance Metrics**: Does the study report on system performance metrics relevant to text transmission (such as transmission speed, error rates, or reliability)?
- **Communication Application**: Does the study demonstrate Li-Fi communication applications in any environment (laboratory, indoor, or outdoor settings)?
- **Publication Type**: Is the study a full research article, systematic review, or meta-analysis (not a conference abstract, editorial, or opinion piece without original research data)?
- **Text/Data Transmission Focus**: Does the study include text or data transmission components (not focusing solely on audio, video, or multimedia transmission without any text/data component)?
- **Li-Fi/VLC Technology Specificity**: Does the study focus on Li-Fi or VLC technology (not other optical communication technologies like infrared or laser communication)?
- **Primary Focus Relevance**: Is Li-Fi or VLC the main focus of the study (not mentioned only peripherally or as a minor component)?

We considered all screening questions together and made a holistic judgment about whether to screen in each paper.

Data extraction:

We asked a large language model to extract each data column below from each paper. We gave the model the extraction instructions shown below for each column:

- **Li-Fi Technology Configuration**:

  Describe the specific Li-Fi technology configuration used in the study, including:
- Transmission medium (e.g., LED type, light spectrum used)
- Transmitter components (e.g., LED, Arduino, microcontroller)
- Receiver components (e.g., photodiode, IR detector)
- Communication method (binary encoding, light modulation technique)

Look in the methods or technical description sections. If multiple configurations are described, list all. Be precise about specific technologies or components used. If any details are unclear or partially described, note this in your extraction.

Example extraction format:

- Transmitter: High-power LED, Arduino Uno, binary encoding (0 = LED OFF, 1 = LED ON)
- Receiver: Photodiode module, IR detector

Data Transmission Characteristics:

Extract specific details about the data transmission:

- Types of data transmitted (text, image, audio).
- Transmission speed or bandwidth.
- Maximum transmission distance.
- Signal encoding method.

Locate this information in the results, methods, or technical performance sections. If multiple data types or speeds are reported, list all. Include units of measurement (Mbps, meters). If exact figures are not provided, note the qualitative description.

Example extraction format:

- Data types: Text, image
- Transmission speed: 100 Mbps
- Maximum distance: 10 meters

Experimental Methodology:

Describe the experimental approach:

- Software used for design/simulation
- Programming languages
- Specific hardware platforms
- Experimental setup and testing protocol.

Search methods, technical implementation, and design sections. Be specific about tools, languages, and experimental approaches. If multiple approaches are used, list comprehensively.

Example extraction format:

- Design software: Proteus 8 Professional
- Programming: C language
- Microcontroller: PIC microcontroller
- Testing protocol: Image and text transmission validation

Performance Outcomes and Limitations:

Extract key performance outcomes and identified limitations:

- Successful transmission results
- Comparative performance (vs. WiFi)
- Technical challenges encountered
- Potential improvements suggested

Look in results, discussion, and conclusion sections. Capture both quantitative performance metrics and qualitative assessments. If multiple outcomes are reported, list comprehensively.

Example extraction format:

- Transmission success: Confirmed text and image transfer
- Comparative performance: Higher security than WiFi
- Limitations: Restricted to line-of-sight communication

Results and discussion:

Visible Light Communication (VLC), commonly referred to as Li-Fi, has emerged as a promising optical wireless communication technology that exploits light-emitting diodes (LEDs) for simultaneous illumination and data transmission. Owing to its inherent advantages, such as high bandwidth availability, enhanced security, immunity to electromagnetic interference, and suitability for indoor environments, Li-Fi has attracted increasing research attention across a wide range of applications, including text, image, audio, video, and vehicle-to-vehicle communications.

Table (1) summarizes the key characteristics of the studies included in this review, highlighting their research focus, hardware configurations, transmitted data types, and reported performance metrics. The surveyed studies demonstrate a strong emphasis on low-cost and prototype-based implementations, typically relying on LEDs, photodiodes or light-dependent resistors (LDRs), and microcontroller platforms such as Arduino and ATmega series. Most works concentrate on text and image transmission, while more recent studies extend VLC applications to multimedia data, including audio and video streams, as well as vehicular communication scenarios.

Table (1): Characteristics of Included Studies

Study	Study Focus	Hardware Configuration	Data Types Transmitted	Performance Metrics	Full text retrieved
Ifada et al., 2019	Low-cost Li-Fi system for text transmission	LED, ATmega16L microcontroller, operational amplifier (OpAmp), photodiode	Text	Qualitative: "top notch" speed, efficiency, security, capacity	No
Ramakrishnan and Nanda kumar, 2023	Image and text transmission via Li-Fi	LED bulb, photodiode receiver	Image, text	10 Mbps (goal: 100 Mbps); high security; line-of-sight limitation	Yes
Zad et al., 2023	Image and text transmission via Li-Fi	LED bulb, photodiode receiver	Image, text	10 Mbps (goal: 100 Mbps); faster than Wi-Fi; range limitation	Yes
Madhuri et al., 2020	Audio and text transmission using Arduino-based Li-Fi	High-power LEDs, Arduino, photodiode module, infrared detector	Audio, text	Qualitative higher speed than Wi-Fi	No
Bolla et al., 2019	Audio and text transmission; indoor services	LEDs (type not specified)	Audio, text	Qualitative: high data rate, durability	No
Sonawane et al., 2022	Complete data transmission (audio, video, text, images)	High-power white LED arrays, control unit, photodiode, light-dependent resistor (LDR)	Audio, video, text, images	Up to 500 Mbit/s (LED), 10 Kbit/s (lamps); short range; high security	Yes
Vasuja et al., 2018	Image and text transmission; prototype design	LED, PIC microcontroller, photodiode/phototransistor	Image, text	Qualitative: higher security than Wi-Fi	No
George et al., 2019	Review of Li-Fi for vehicle-to-vehicle communication	No mention found	No mention found	Qualitative: secure, efficient, high rate	No
Begam et al., 2021	Arduino-based alpha-numeric and image transmission	LED, Arduino, keypad, light-dependent resistor (LDR)/photodiode	Alpha-numeric, image	Qualitative: successful transfer; implied line-of-sight restriction	No
Ali Abdulsalm et al., 2015	Vehicle-to-vehicle communication prototype	LED bulbs	No mention found	Qualitative: initial results positive; simulation and experiment agree	No

In terms of performance, the reviewed literature reports a wide range of outcomes, from qualitative assessments, such as improved security and higher data rates compared to Wi-Fi, to quantitative metrics reaching up to several hundred megabits per second under controlled conditions. However, the table also reveals notable variability in experimental rigor, documentation completeness, and availability of full-text sources. Collectively, these characteristics underline both the practical potential of Li-Fi systems and the existing gaps in standardized evaluation and reporting, thereby motivating further systematic analysis and optimization of VLC-based data transmission frameworks.

Data types transmitted:

- Text only: One study
- Image and text: Three studies
- Audio and text: Two studies
- Audio, video, text, images: One study
- Alpha-numeric and image: One study
- We didn't find mention of the data type in Two studies

Performance metrics:

- Quantitative data rates were reported in Thtee studies:10Mbps (Two studies), up to 500Mbit/s (One study), and 10Kbit/s (lamps,One study)
- Nine studies included only qualitative performance descriptions (e.g., "high speed", "efficient", "secure"), with some overlap with quantitative reporting
- Security was mentioned as a feature in Five studies
- Limitations such as range or line-of-sight requirements were mentioned in Four studies
- We didn't find mention of any studies without at least qualitative performance metrics

Text transmission in visible light communication (VLC) and LED-based optical wireless systems relies fundamentally on the choice of encoding and modulation techniques, which directly affect data integrity, transmission efficiency, system complexity, and implementation cost. Encoding schemes define how textual or digital information is represented in binary or symbolic form, while modulation techniques govern how this information is physically conveyed through variations in light intensity, switching states, or temporal patterns of LEDs.

Table (2) presents a comparative overview of prior studies that have employed different text transmission, encoding, and modulation approaches in LED-based communication systems. The reviewed literature reveals a predominance of simple binary encoding schemes, most commonly LED ON/OFF signaling and on–off keying (OOK), owing to their ease of implementation on low-cost microcontrollers such as Arduino and ATmega platforms. Several studies rely on light intensity modulation without explicitly defining the underlying binary mapping, while others mention VLC applications without providing sufficient technical detail regarding encoding or modulation mechanisms.

Table (2): Text Transmission/Methods Encoding and Modulation Techniques

Study	Encoding/Modulation Method	Notes
Ifada et al., 2019	Binary encoding (LED on/off)	ATmega16L microcontroller; no advanced modulation
Ramakrishnan and Nanda kumar, 2023	Light intensity modulation	Varying LED current: no explicit binary encoding
Zad et al., 2023	Light intensity modulation	As above
Madhuri et al., 2020	Binary encoding (LED on/off)	Arduino-based; explicit binary mapping
Bolla et al., 2019	No mention found	Only general mention of visible light
Sonawane et al., 2022	Binary encoding (Morse code, 0/1)	On-off keying; mentions Morse code
Vasuja et al., 2018	No explici description found	Implied software encoding in C
George et al., 2019	No mention found	Review; no technical details
Begam et al., 2021	No explicit mention found	Implied binary via LED/light-dependent resistor (LDR)
Al Abdulsalam et al., 2015	No mention found	No encoding details

Overall, the table 2 highlights a clear trend toward low-complexity, intensity-based modulation techniques, alongside a noticeable lack of standardized or well-documented encoding methodologies in a significant portion of the literature. This gap underscores the need for clearer specification, systematic comparison, and optimization of encoding and modulation strategies to enhance the reliability and scalability of text transmission in VLC systems.

Hardware implementation plays a central role in determining the performance, reliability, and practicality of visible light communication (VLC) and Li-Fi systems. Beyond modulation and encoding strategies, the selection and integration of transmitter components, optical receivers, and control or processing platforms directly influence achievable data rates, transmission range, system robustness, and overall cost. Consequently, a clear understanding of prevailing hardware implementation approaches is essential for evaluating the current state of VLC-based communication systems.

Table (3) presents a comparative overview of the hardware architectures employed in the reviewed studies, focusing on the transmitter, receiver, and control/processing subsystems. The table captures the diversity of design choices adopted in experimental and prototype-based implementations, ranging from simple LED–photodiode links to more structured systems incorporating microcontrollers, high-power LED arrays, and software-based interfaces. By synthesizing these elements, the table provides insight into common design trends as well as variations in implementation complexity.

Table (3) provides a structured comparison of the hardware implementation approaches adopted in the reviewed VLC/Li-Fi studies by separating each prototype into three functional blocks: the transmitter, the receiver, and the control/processing layer. In general, the table indicates that most implementations rely on low-cost, readily available optical components, while the level of technical detail reported for control and processing varies considerably across studies.

From the transmitter perspective, the dominant trend is the use of LED-based sources, either in the form of standard LED bulbs or discrete LEDs and LED arrays. Several studies employ simple LED bulb transmitters, reflecting a practical design choice that prioritizes availability and ease of deployment. In contrast, other works adopt high-power LEDs or LED arrays, which typically support higher optical power budgets and potentially improved link stability, but also imply more stringent requirements in driver circuitry and thermal management. A notable example is the inclusion of a microcontroller-driven LED transmitter combined with an operational amplifier stage, suggesting additional analog conditioning and more deliberate signal shaping at the transmission side.

Table (3): Hardware Implementation Approaches

Study	Transmitter	Receiver	Control/Processing
Ifada et al., 2019	LED, ATmega16L, operational amplifier (OpAmp)	Photodiode	Java interface
Ramakrishnan and Nanda kumar, 2023	LED bulb	Photodiode	No mention found
Zad et al., 2023	LED bulb	Photodiode	No mention found
Madhuri et al.,2020	High-power LEDs, Arduino	Photodiode, infrared detector	Arduino IDE
Bolla et al., 2019	LEDs	No mention found	No mention found
Sonawane et al., 2022	High-power LED arrays, control unit	Photodiode, light-dependent resistor (LDR)	Visual Basic Runtime
Vasuja et al., 2018	LED, PIC microcontroller	Photodiode/phototr ansistor	C language, Proteus 8
George et al., 2019	No mention found	No mention found	No mention found
Begam et al., 2021	LED, Arduino, keypad	light-dependent resistor (LDR)/photodiode	No mention found
Al Abdulsalam et al., 2015	LED bulbs	No mention found	Proteus package

Regarding the receiver, photodiodes represent the most common detection element across the included studies, consistent with their suitability for intensity modulation-based communication due to their relatively fast response and improved sensitivity. Some studies also incorporate light-dependent resistors (LDRs), either as alternatives or complementary sensors. While LDRs are cost-effective and simple to interface, they are typically associated with slower response times and therefore may constrain achievable data rates or modulation bandwidth. Importantly, multiple studies provide no explicit description of the receiver configuration, which limits reproducibility and weakens the ability to compare performance outcomes across the literature.

The control and processing layer is the least consistently documented component in the reviewed studies. Where details are provided, the implementation environments reflect common prototyping ecosystems, including Arduino IDE-based development, C-language programming supported by Proteus simulation tools, and desktop-level interfaces such as Java or Visual Basic runtime. However, the frequent absence of information on the processing platform, decoding workflow, synchronization approach, or software architecture represents a methodological gap, particularly because these factors strongly influence end-to-end latency, decoding reliability, and system robustness.

Collectively, the table suggests that existing Li-Fi/VLC prototypes largely converge on a conventional architecture, LED transmitter and photodiode receiver, implemented with microcontroller-based or PC-assisted processing. At the same time, the table highlights a clear limitation in the literature: inconsistent reporting of hardware and processing details, especially at the receiver and control layers, which constrains systematic benchmarking and makes it difficult to attribute performance differences to specific design choices.

Transmitter:

- Seven studies used some form of LED as the transmitter (including LED, LED bulb, LED bulbs, LEDs, high-power LEDs, and high-power LED arrays).
- Two studies used microcontrollers or control units as part of the transmitter (ATmega16L, PIC microcontroller, Arduino, control unit).

Receiver:

- Photodiode was the most common receiver, found in seven studies.
- Two studies used light-dependent resistors (LDR) as a receiver.
- One study used an infrared detector.
- One study used a phototransistor.

Control/Processing:

- Java interface, Arduino IDE, Visual Basic Runtime, C language, Proteus 8, and Proteus package were each used in one study.
- We didn't find mention of control/processing information for four studies.

Typical pairings:

- Six studies paired an LED or LED bulb transmitter with a photodiode receiver.
- Two studies paired high-power LEDs or arrays with photodiode or LDR receivers.
- Other combinations (including phototransistor, infrared detector, control unit, keypad) were found in three studies.
- We didn't find mention of receiver information for three studies.

Overall, photodiode was the most common receiver, and LED-based transmitters were used in most studies Control/processing approaches varied, and we didn't find this information for several studies.

Table (4) compares the reported data transmission rates across the included VLC/Li-Fi studies and, importantly, exposes a central limitation in the literature: most papers do not provide quantified throughput, relying instead on qualitative claims (e.g., “high data rate,” “top notch,” or “better than Wi-Fi”). This uneven reporting constrains objective benchmarking and makes cross-study performance comparisons difficult.

Table (4): Performance Analysis Data Transmission Rates

Study	Data Rate	Notes
Ifada et al., 2019	No mention found	Qualitative: "top notch"
Ramakrishnan and Nanda kumar, 2023	10 Mbps (goal:100 Mbps)	Explicitly reported
Zad et al., 2023	10 Mbps (goal:100 Mbps)	Explicitly reported
Madhuri et al., 2020	No mention found	Qualitative: higher than Wi-Fi
Bolla et al., 2019	No mention found	Qualitative: high data rate
Sonawane et al., 2022	Up to 500 Mbit/s (LED),10 Kbit/s lamps	Explicitly reported
Vasuja et al., 2018	No mention found	Qualitative: better than Wi-Fi
George et al., 2019	No mention found	Qualitative: very high rates
Begam et al., 2021	No mention found	No mention found
Ali Abdulsalam et al., 2015	No mention found	No mention found

Overall, Table (4) indicates that quantitative throughput reporting is the exception rather than the norm in this body of work. The table therefore highlights a methodological gap: future studies should standardize the reporting of data rate using clearly defined experimental conditions (e.g., modulation method, distance, ambient light, receiver type, bandwidth, and error performance). Without these details, claims of "high" speed remain largely non-comparable and reduce the evidentiary strength of performance evaluations in VLC/Li-Fi research.

- Explicit quantitative data rate values were found in three out of ten studies:
- Two studies reported 10Mbps (with a goal of 100 Mbps)
- One study reported up to 500 Mbit/s (LED) and 10 Kbit/s (lamps)
- Only qualitative descriptions of data rate were found in five studies, using phrases such as "top notch", "higher than Wi-Fi" ,"high data rate", "better than Wi-Fi", and "very high rates".
- We didn't find mention of data rate information in two studies.

Transmission distance and signal quality are key performance dimensions in visible light communication (VLC) and Li-Fi systems, as they directly determine link reliability, coverage area, and suitability for practical deployment. Unlike conventional radio-frequency systems, VLC performance is strongly constrained by line-of-sight conditions, optical power levels, ambient light interference, and receiver sensitivity. Consequently, evaluating communication distance alongside signal quality metrics is essential for understanding the operational limits of VLC-based prototypes.

Table (5) presents a comparative overview of the implementation type, achieved data rate, maximum communication distance, and signal quality indicators reported in the reviewed studies. The table highlights how most existing works focus on prototype-level implementations, with performance assessment often emphasizing qualitative indicators such as security, interference resistance, and durability rather than precise quantitative measurements. By consolidating these aspects, the table provides insight into how distance and signal quality are addressed in current VLC research, while also revealing gaps in standardized reporting that limit direct comparison across studies.

Table (5): Distance and Signal Quality

Study	Implementation Type	Data Rate	Maximum Distance	Signal Quality Metrics
Ifada et al., 2019	Prototype	No mention found	No mention found	Qualitative: efficient, secure
Ramakrishnan and Nanda kumar, 2023	Prototype	10 Mbps	No mention found	Minimal interference; high security
Zad et al., 2023	Prototype	10 Mbps	No mention found	Minimal interference; high security
Madhuri et al., 2020	Prototype	No mention found	No mention found	Qualitative: high speed
Bolla et al., 2019	Prototype	No mention found	No mention found	Qualitative: high durability
Sonawane et al., 2022	Prototype	Up to 500 Mbit/s (LED)	Short distances	Bit error rate, noise management
Vasuja et al., 2018	Prototype	No mention found	No mention found	Qualitative: higher security
George et al.,2019	Review/demo	No mention found	No mention found	Qualitative: secure, efficient
Begam et al., 2021	Prototype	No mention found	No mention found	Implied line-of-sight restriction
Ali Abdulsalam et al., 2015	Prototype	No mention found	No mention found	Qualitative: simulation and experiment agree

- Data rate was not mentioned in seven out of ten studies. Of the remaining studies, two reported a data rate of10Mbps, and one reported a data rate of up to 500 Mbit/s (using LED).
- For signal quality metrics, six studies provided only qualitative descriptions such as "efficient," "secure," "highspeed," "high durability," or "higher security." Two studies reported "minimal interference" and "high security." One study reported quantitative metrics, specifically bit error rate and noise management. One study implied a line-of-sight restriction, and one study stated that simulation and experiment results agreed.
- We did not find mention of quantitative signal quality metrics (such as bit error rate) in nine out of ten studies; only one study reported these metrics.

Table (6) presents a comparative overview of system architecture variations at the transmitter side, focusing on the specific components employed and the corresponding implementation notes reported in prior studies. The table highlights the spectrum of design approaches, ranging from simple LED bulb–based transmitters with minimal control logic to more structured architectures incorporating microcontrollers, operational amplifiers, and high-power LED arrays. This comparison enables identification of dominant design trends as well as gaps in documentation across the reviewed literature.

Table (6): System Architecture Variations Transmitter Configurations

Study	Transmitter Components	Notes
Ifada et al., 2019	LED, ATmega16L, operational amplifier (OpAmp)	Off-the-shelf, cost-effective
Ramakrishnan and Nanda kumar, 2023	LED bulb	No microcontroller mentioned
Zad et al., 2023	LED bulb	No microcontroller mentioned
Madhuri et al., 2020	High-power LEDs, Arduino	Arduino IDE
Bolla et al., 2019	LEDs	No further details
Sonawane et al., 2022	High-power LED arrays, control unit	PC interface
Vasuja et al., 2018	LED, PIC microcontroller	Proteus 8, C language
George et al., 2019	No mention found	Review
Begam et al., 2021	LED, Arduino, keypad	No mention found
Al Abdulsalam et al., 2015	LED bulbs	No mention found

The comparison in Table (6) reveals that most VLC/Li-Fi studies favor simplified transmitter configurations, often based on readily available LED bulbs or discrete LEDs, reflecting a strong emphasis on cost-effectiveness and ease of prototyping. More advanced designs, such as those integrating microcontrollers, operational amplifiers, or high-power LED arrays, are less common but indicate greater attention to signal control, modulation precision, and system scalability. However, several studies provide limited or no detail regarding transmitter components, which restricts reproducibility and hinders systematic performance comparison.

Overall, the findings suggest that while basic LED-based transmitter architectures are sufficient for proof-of-concept demonstrations, achieving higher performance and robustness in VLC systems requires more explicitly defined and carefully engineered transmitter designs. Future research would benefit from standardized reporting of transmitter configurations and clearer justification of component selection, particularly as VLC technologies progress from experimental prototypes toward practical deployment.

Microcontroller or control unit:

- Two studies used Arduino (Madhuri et al.,2020; Begam et al.,2021)
- One study used ATmega16L (Ifada et al.,2019)
- One study used a PIC microcontroller (Vasuja et al.,2018)
- One study mentioned a control unit but did not specify the type (Sonawane et al.,2022)
- We didn't find mention of a microcontroller or control unit in four studies (Ramakrishnan and Nanda kumar,2023; Zad et al.,2023; Bolla et al.,2019; Al Abdulsalam et al.,2015)
- We didn't find mention of transmitter component details for one study (George et al.,2019)

Other transmitter components:

- One study included an operational amplifier (OpAmp) (Ifada et al.,2019)
- One study included a keypad (Begam et al.,2021)
- One study included a PC interface (Sonawane et al.,2022)
- One study described the transmitter as off-the-shelf and cost-effective (Ifada et al., 2019)

The receiver subsystem is a critical component in visible light communication (VLC) and Li-Fi systems, as it directly determines the accuracy, sensitivity, and robustness of optical signal detection and decoding. Receiver design influences key performance parameters such as achievable data rate, noise tolerance, bit error performance, and resilience to ambient light interference. Therefore, examining receiver design approaches provides essential insight into the practical limitations and capabilities of VLC-based communication systems.

Table (7) presents a comparative overview of the receiver design approaches adopted in the reviewed studies, focusing on the types of optical sensors used and the associated implementation notes. The table highlights the prevalence of photodiode-based receivers, alongside alternative or complementary sensing elements such as light-dependent resistors (LDRs) and phototransistors. By consolidating these design choices, the table enables identification of common trends, levels of design sophistication, and gaps in reporting across the VLC literature.

Table (7): Receiver Design Approaches

Study	Receiver Components	Notes
Ifada et al.,2019	Photodiode	Java interface for monitoring
Ramakrishnan and Nanda kumar, 2023	Photodiode receiver	No mention found
Zad et al.,2023	Photodiode receiver	No mention found
Madhuri et al.,2020	Photodiode module, infrared detector	Arduino-based
Bolla et al.,2019	No mention found	No mention found
Sonawane et al.,2022	Photodiode, light-dependent resistor (LDR)	Signal conditioning, UART
Vasuja et al.,2018	Photodiode/phototransistor	No mention found
George et al.,2019	No mention found	No mention found
Begam et al.,2021	light-dependent resistor (LDR)/photodiode	No mention found
Ali Abdulsalam et al.,2015	No mention found	No mention found

The comparison in Table (7) indicates that photodiodes are the dominant receiver component in most VLC/Li-Fi implementations, reflecting their suitability for high-speed optical detection and relatively linear response characteristics. In several studies, photodiodes are combined with additional elements such as LDRs or phototransistors to support simplified detection or hybrid sensing strategies. More advanced implementations incorporate signal conditioning and digital interfaces, suggesting improved attention to noise mitigation and data integrity. However, a substantial number of studies provide limited or no information regarding receiver design details, which significantly restricts reproducibility and comparative performance evaluation. The absence of standardized reporting on receiver components, conditioning circuits, and interfacing methods represents a notable gap in the literature. Future research should emphasize detailed and quantitative documentation of receiver architectures to facilitate benchmarking and to support the advancement of VLC systems from experimental prototypes to reliable, real-world communication solutions.

Conclusion:

The reviewed studies collectively highlight the transformative potential of Li-Fi technology in wireless communication. By leveraging visible light for data transmission, Li-Fi offers significant advantages in terms of bandwidth, speed, and security compared to traditional RF-based systems like Wi-Fi. However, the literature also reveals disparities in research focus, ranging from modulation techniques and system architecture to practical deployment challenges and environmental limitations. While some studies emphasize theoretical performance, others explore real-world applications in healthcare, transportation, and smart infrastructure. Overall, Li-Fi is positioned as a promising complement, not a replacement, to existing wireless technologies.

Recommendations:

- **Expand Real-World Testing**: Future research should prioritize large-scale, real-environment deployments to validate theoretical models and assess performance under diverse conditions.
- **Develop Hybrid Systems**: Integrating Li-Fi with Wi-Fi and 5G can ensure seamless connectivity and mitigate the limitations of line-of-sight requirements.
- **Address Technical Barriers**: Continued innovation is needed to overcome challenges such as signal obstruction, ambient light interference, and limited range.
- **Standardization and Regulation**: Establishing global standards and protocols will be essential for interoperability and widespread adoption.
- **Focus on Security and Privacy**: Given its confined transmission area, Li-Fi offers inherent security benefits, but further research should explore encryption and authentication mechanisms tailored to optical communication.

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