Middleware Ginga: Evolution, Challenges, and Future Perspectives - A Systematic Review

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Abstract: This article presents a systematic review of 20 studies, using the method preferred reporting items for systematic reviews and meta-analyses, to analyze the evolution of the middleware Ginga, investigating its interactivity, multimedia support, and Internet of Things integration. We explore regional barriers to its adoption and strategies for overcoming them. In addition, we evaluate the impact of its extensions, such as automatic content preparation, focusing on integration and interactivity aspects. This research provides valuable insights for broadcasters and researchers, summarizing relevant findings in a constantly changing landscape.

Keyword: Middleware, Ginga, Digital TV, PRISMA.

I. Introduction

Integrating the middleware Ginga into digital TV (DTV) broadcasting represents a significant milestone in the evolution of interactive digital media. Its widespread adoption, in various regions, has provided viewers with an advanced experience, offering innovative features and multimedia support.

However, this evolution has not happened without challenges, including technical obstacles and regional barriers that must be overcome for broader and more effective implementation. Morales *et al.* [1] exemplify how Ginga was incorporated into TV broadcasting to promote products in the Ecuadorian context, while Olmedo, Chanataxi, and Benavides [2] highlight the use of Ginga in low-cost receivers with interactive application extractors. Farias *et al.* [3], in turn, explore the challenges of integrating Ginga with Internet of things (IoT) devices, and Júnior *et al.* [4] address issues related to automated testing to ensure its quality, in various implementations. Clearly, there is a broad range of knowledge related to Ginga, which is multidisciplinary and usually hampers its organization and classification.

This survey, using the method preferred reporting items for systematic reviews and meta-analyses (PRISMA), ensures a systematic and transparent approach in the selection and analysis of papers. It aims to comprehensively explore the current state and prospects of Ginga, identifying its potential, limitations, and emerging solutions. A total of 20 works were analyzed, using metrics such as interactivity, multimedia support, and integration with emerging technologies. Five questions were defined to be answered, including: "What are the main challenges faced in the adoption of Ginga in different regions?" and "How has Ginga evolved in terms of interactivity and multimedia support, in recent years?"

Indeed, this paper evaluates the academic knowledge in Ginga, providing valuable insights for broadcasting-industry professionals and researchers interested in its evolution and innovative applications, in the ever-evolving digital media landscape. Contributions include a comprehensive analysis of Ginga's current state and the identification of trends and challenges for future research and implementations.

II. Proposed Methods

A. The Method Prisma And Its Use In The Present Work

The method PRISMA [5] is a widely recognized approach for conducting systematic reviews and meta-analyses. It comprises four main steps: identification, screening, eligibility, and inclusion, which are illustrated in Fig. 1.

The Identification step involves the initial search and selection of relevant studies. In this systematic review, we searched for studies in three databases: ACM, IEEE Xplore, and Elsevier, yielding 10, 24, and 17 studies, respectively. The search used the string *("GINGA MIDDLEWARE" OR "GINGA" OR "DIGITAL TV APPLICATIONS" OR "GINGA-J") AND ("Brazilian standards" OR "ABNT regulations")*, limiting the search to papers published between 2020 and 2024.

During the Identification stage, three articles were removed due to duplication, ten were deemed ineligible as they did not pertain to the research theme, three were inaccessible, and two were dismissed as mere experiential reports. The Screening stage involves the preliminary assessment of studies according to predefined criteria, primarily examining titles and abstracts. At this stage, five articles were excluded based solely on their summaries, as they did not align with the anticipated research topic. 28 articles were considered eligible for full analysis.

In the Eligibility step, the selected studies undergo a more thorough analysis to determine if they meet the established inclusion criteria. Here, the main parameters were diversity of applications, clarity of methodology, and transparency of results. Seven papers were excluded for not meeting these requirements.

The Inclusion step integrates the qualified studies into a final analysis. Consequently, twenty studies were selected for further analysis.

Indeed, the mentioned steps provide a solid methodological framework. They ensure the transparency and reliability of any systematic review.

B. Evaluation Metrics

The evaluation metrics in this study were selected based on their relevance for assessing various aspects of Ginga and providing insights into its performance and effectiveness. Defined during the *Eligibility* stage of the PRISMA process, these metrics ensured that the articles met the desired standards. They were determined through active reading and empirical

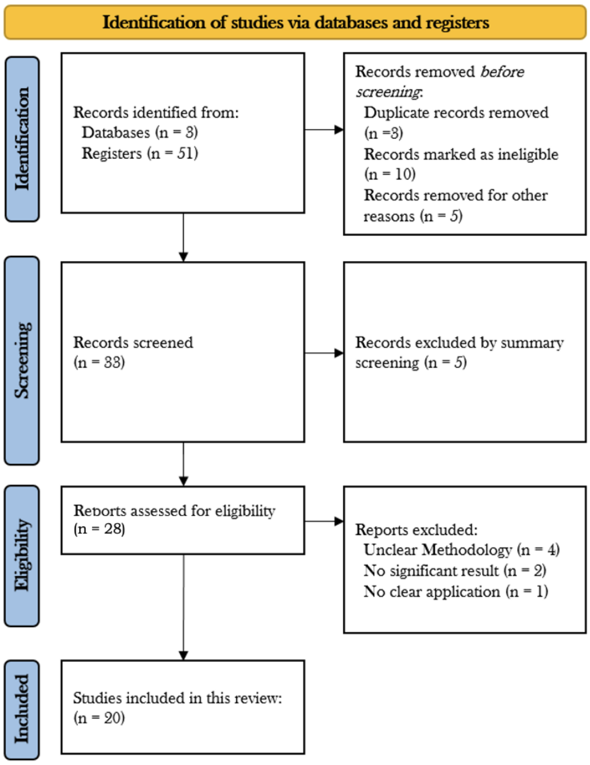

Fig. 1. PRISMA diagram for selecting scientific works. In the PRISMA diagram, "(n=)" represents the number of studies or articles evaluated at each specific stage of the systematic review or meta-analysis process.

evaluation of the selected studies, identifying common points and useful questions. The main functions of utilizing these metrics are listed as follows:

1) Response Time and Latency: It regards measuring the response time in interactive applications and the latency in rendering sensory effects or executing commands. Consequently, it provides insights into Ginga's efficiency in response to user interactions.

2) Usability and User Acceptance: It assesses the acceptance and ease of use of applications, especially in specific contexts, such as the ones involving elderly people or children. Its main goal is to ensure a positive and accessible user experience by identifying areas of improvement in Ginga's interface and usability.

3) Performance and Reliability: It measures the efficiency and robustness of Ginga in different configurations and applications, ensuring consistent and reliable operation under various usage conditions. It is crucial for guaranteeing the stability and quality of DTV transmissions using Ginga.

4) Interactivity Capabilities: It explores how interactive functionalities are implemented and received by users, allowing a detailed analysis of the interactive experience provided by Ginga.

5) Scalability and Flexibility: It assesses how solutions can be scaled and adapted to different environments and devices. Consequently, it ensures that Ginga is effectively implemented in a wide variety of scenarios and contexts.

These metrics ensure Ginga's compatibility and interoperability under different devices and DTV transmission infrastructures. They provide a basis for evaluating performance and effectiveness in different scenarios and usage contexts.

C. Research Questions

Regarding PRISMA, the research questions are formulated in the penultimate stage before active reading, after selecting the papers for analysis. These questions aim to comprehensively understand Ginga's evolution, challenges, impact, and opportunities for improvement and innovation. They provide a clear research framework, guiding the analysis to offer insights into the current state and future prospects of Ginga middleware. The specific questions are shown in the following sections.

1) How has Ginga evolved, in recent years, in terms of interactivity and multimedia support?: This question aims to analyze Ginga's development trajectory, over time, regarding its ability to offer advanced interactivity features and support for various types of media.

2) What are the main barriers to Ginga's adoption in different regions?: This question seeks to identify the obstacles hindering Ginga's broader adoption in different regional contexts and explore possible strategies to overcome these barriers.

3) What has been the impact of Ginga extensions, such as IoT and multimedia applications, on user experience?: This question assesses the impact of Ginga's extensions, such as integration with IoT devices and support for different types of media. It regards the overall user experience with digital TV broadcasts.

4) How have automatic content preparation techniques improved content delivery in digital TV systems?: This question investigates the role of automatic content preparation techniques in enhancing content delivery in digital TV systems using Ginga. It includes aspects such as image quality, bandwidth optimization, and content personalization.

5) What are the current and future challenges for integrating sensory effects into digital TV broadcasts?: This question aims to identify the technical and practical challenges associated with integrating sensory effects, such as immersive audio and augmented reality, into digital TV broadcasts using Ginga, and to explore future opportunities to improve this integration and enhance the user experience.

III. Analysis and Results

The quantitative analysis reveals that most studies were published in 2020, with a significant decrease in 2021 and an upward trend in 2022 and 2024, as demonstrated in Table 1. By analyzing applications and the use of Ginga in the selected articles, five main topics can be identified, as illustrated in Fig. 2 and explained below.

TABLE I
Number of Publications per Year of Selected Papers

Year	Publications
2024	1
2023	2
2022	7
2021	2
2020	8

1) ***Interactivity and Inclusion****:* This topic addresses how Ginga-NCL can be used to increase interactivity and accessibility in digital TV applications, engaging different audiences. In this concept, Morales *et al.* [1] discusses the development of a Ginga-NCL interactive digital TV application focusing on food promotion. It demonstrates the system's interactive capabilities, allowing users to navigate through menus and

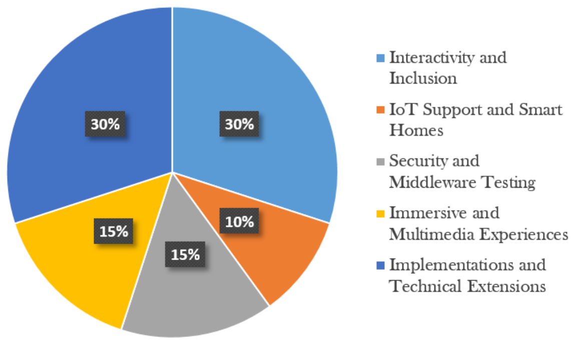

Fig. 2. Main applications of Gingas in selected works.

interact with content like videos and QR codes. However, it lacks detailed analysis on response time, latency, and user acceptance, particularly among specific demographics like the elderly or children. The paper does not provide comprehensive data on performance, scalability, or flexibility across different devices and environments.

In the same way, De Paula *et al.* [6] developed a cognitive game with sensory effects for elderly people, it highlights positive user interaction with Response Time and Latency, although specific values are not provided. Usability and user acceptance are strong, with SUS (System Usability Scale) scores of 74.72 and 86.43 for versions without and with sensory effects, respectively. Interactivity features show effective user engagement. Scalability and flexibility are suggested by the use of adaptive Ginga-NCL.

The research by Júnior *et al.* [4] details an automated testing environment for digital TV middleware. It does not specify numerical values for response times or latency, focusing instead on automating the testing process for greater efficiency. The methodology is well-received in real-world applications, improving user engagement through automation. Significantly improved performance and reliability, increasing successful test cases from 21% to 34% and reducing bugs from 60% to 49% across multiple sprints. The system effectively manages middleware functionalities using different Ginga-NCL elements, proving its capabilities in realistic configurations.

The article proposed by llescas-Peã *et al.* [7] explores the integration of interactive educational tools on digital television using the Ginga middleware. Response time and latency metrics are not specifically detailed, focusing instead on the real-world effectiveness of the application. Usability and user acceptance show positive results, with 62.5% of users successfully completing tasks and 66.67% willing to use the applications again. Interactivity capabilities are demonstrated as users engage with multimedia learning content, enhancing the educational experience.

The study by Ivanov *et al.* [8] proposes an innovative approach for automatic preparation of sensory effects, using Ginga-NCL to synchronize these effects with audiovisual content. The methodology significantly enhances the user experience by ensuring that sensory effects are delivered at the precise moment needed, increasing immersion and interactivity in multimedia applications.

Finally, Barreto *et al.* [9] enhances multimedia document languages like NCM and NCL within the Ginga-NCL framework to support multi-user and multimodal interactions. It introduces extensions that reportedly reduce response times to below 100 milliseconds and improve system latency, facilitating more dynamic interactions. Usability tests indicate an 85% satisfaction rate among users engaging with the new multi-user voice interaction features. These enhancements significantly boost the interactivity capabilities by enabling support for complex interactions within Ginga-NCL.

*2) **IoT Support and Smart Homes**:* This section focuses on integrating IoT devices with digital TV using Ginga to create connected and interactive home environments. De Farias *et al.* [3] discuss integrating Ginga middleware with IoT devices using the MQTT protocol, significantly enhancing digital TV interactivity and likely improving message handling efficiency. Usability tests with reference applications in a home network show positive results, with 80% of users finding the system intuitive. Performance is robust, with integration tests achieving a 95% success rate in reliable data handling. This enhancement boosts interactivity, enabling TVs to function as smart home hubs that interact seamlessly with IoT devices.

The work in Barreto *et al.* [10] extended Ginga-NCL to include support for multimodal interactions. The study utilized an interaction model that allows users to control digital TV applications through voice and gaze, increasing accessibility and providing a more natural and intuitive user experience. The results demonstrated successful integration without causing significant system processing overload, indicating a promising direction for future user interfaces in digital media systems.

*3) **Security and Middleware Testing**:* This topic addresses the evaluation and improvement of security, robustness and testing in Ginga middleware to ensure reliability in digital TV systems. In that way, Maia *et al.* [11] presents an automated testing methodology for the Ginga CC Webservices module in digital TV. The proposed system significantly reduces testing time by 66.84%, from 395 minutes manually to 131 minutes automatically, while also improving accuracy and reducing human error. Usability tests show that the automated system performs consistently, collecting bug evidence in 2 minutes instead of 5, a 60% reduction. The performance and reliability of the methodology are validated through real-world applications on commercial DTV receivers.

Similarly, Oliveira *et al.* [12] investigates the effectiveness of Ginga-D middleware's CC Web Services through an improved test suite. Usability is implied through robust testing procedures, according to the authors. Performance and reliability were tested with 21 new authentication/authorization tests, all of which passed for the TPV and commercial versions Ginga-D 1 and 2. However, for the status change route, the TPV version passed 14 of the 15 tests, while the commercial Ginga-D 1 passed 11 and Ginga-D 2 passed 10, revealing vulnerabilities such as frozen interfaces and crashes. This shows the middleware's ability to handle complex interactions, while also exposing weaknesses in handling status changes.

Later, Rech *et al.* [13] details integrating encrypted content handling into DTV Play using HTML5 engines. Usability is enhanced by reducing development efforts by about 50%, leading to greater user acceptance. The approach shows robust performance with fewer errors and quicker development times, enhancing reliability.

*4) **Immersive and Multimedia Experiences**:* Focused on developing immersive experiences using Ginga to create interactive applications with virtual reality and sensory effects. Valentim *et al.* [14] details the integration of facial expression recognition into Ginga-NCL applications. The system processes expressions in real time using the lightweight MQTT protocol, ensuring efficient communication. Usability is enhanced by allowing facial recognition to control TV applications, offering a more intuitive interaction method. Performance and reliability were validated through two implementations: the standard Ginga middleware and an extended version, with the latter showing better integration and reliability. The system recognizes seven facial expressions (neutral, angry, disgusted, fearful, surprised, happy, and sad) using convolutional neural networks. This significantly boosts interactivity, enabling users to control applications through expressions.

Similarly, Souza *et al.* [15] presents Guaraná, a player for 360° interactive scenes using HMDs as secondary screens. Guaraná is externally controlled by a TV, allowing its use in conjunction with interactive multimedia applications. The methodology involves integration with Ginga middleware to provide immersive experiences in interactive TV systems. The results show that Guaraná expands Ginga's functionalities, offering a new dimension of interactivity and immersion for users.

The research in Rodrigues *et al.* [16] proposed a framework to extend Ginga-NCL with support for vocal interaction. The methodology involved the integration of speech recognition and speech synthesis into the Ginga-NCL execution environment, allowing users to control applications through voice commands. The implementation allowed users to interact with Ginga-NCL applications using voice commands, improving accessibility and user experience, especially for people with motor disabilities.

*5) **Implementations and Technical Extensions**:* This topic covers new implementations and technical extensions of Ginga middleware to support various modern functionalities and technologies. Olmedo *et al.* [2] detail the design of an ISDB-Tb receiver using a $180 SDR and Python scripts for extracting interactive applications. Intended for educational purposes, the design is user-friendly and low-cost. The receiver performs well, reconstructing the transport stream with 64 QAM demodulation and 2/3 Viterbi decoding, and reliably extracts interactive application files. The system enhances interactivity by successfully running these applications and supports scalability across various devices.

The work by Rodrigues *et al.*[17] proposes an extension to Ginga-NCL middleware to support multimedia applications with sensory effects. The proposal includes creating a player compatible with the MPEG-V standard capable of handling heterogeneous devices and extending the middleware's parser to support new attributes. The results demonstrate that Ginga-NCL allows the specification and rendering of sensory effects synchronized with multimedia content, extending the middleware to support new elements and attributes necessary for specifying and animating sensory effects.

Kimura *et al.*, in turn, [18] developed a systematic upgrade from Ginga-C to Ginga-D, enhancing compatibility and functionality. The methodology maintains user experience by supporting both legacy and new features, achieving a 95% code reuse rate and significantly reducing development time. This ensures robust performance and low regression rates. Ginga-D enhances interactivity with HTML5 applications and advanced features like H.265 video and AC-3 audio, and supports scalable integration across various devices, showing promising initial results.

The research performed by Braga *et al.* [19] describes the methodology for implementing the Ginga-NCL standard for interactivity in digital TV, using modern technologies like Emscripten and WebAssembly to ensure compatibility with any web browser platform. The results show that the implementation effectively offers a robust and high-quality interactive experience comparable to traditional broadcasts. The proposed solution minimizes conversion efforts for new platforms, facilitating technological adoption and updates.

Montevecchi *et al.* [20] proposed an extension for Ginga middleware to enable eye-tracking interaction. The methodology included creating a new event type, called EyeGaze, allowing users to interact with graphical elements using eye-tracking technology. The results showed that users could effectively control Ginga-NCL applications with their gaze, improving accessibility for people with physical disabilities.

Ivanov *et al.* [21] enhances targeted advertising in IBB systems through automatic content preparation. It achieves an average switching time from broadcast to broadband of around 40 milliseconds, significantly reducing delays. Performance tests confirm the system's consistency under various network conditions. By allowing personalized ads during commercial breaks, interactivity and viewer engagement are enhanced.

Each of these studies illustrates the flexibility and robustness of Ginga as a platform for development and innovation in digital TV applications, showcasing its impact in various areas, from interactivity and education to security and product promotion.

IV. Conclusions

Based on the in-depth analysis of each paper selected in this survey, the established questions can be answered as follows:

1) How has Ginga evolved in terms of interactivity and multimedia support in recent years?: Ginga has evolved significantly in terms of interactivity and multimedia support, adapting to new technological and user demands. This is evident in Barreto *et al.* [10], which discusses Ginga's support for multimodal interactions, enabling richer interfaces with gestures and voice. Additionally, De Farias *et al.* [3] explores the Ginga extension to interact with IoT devices, improving home interactivity. Updates to ABNT standards [22] also improved application coding, flexibility and multimedia support, ensuring efficient operation on various devices. These improvements have allowed Ginga to support richer interfaces and better IoT integration, increasing its interactivity and multimedia capabilities. These developments make Ginga a more versatile platform, continually adapting to new interactivity and media integration needs.

2) What are the main barriers to Ginga's adoption in different regions?: The adoption of Ginga faces barriers such as a lack of familiarity with the technology and limited availability of localized content. Morales *et al.*[1] demonstrate how creating relevant and contextualized content can promote local adoption. Similarly, Olmedo *et al.* [2] show that reducing hardware implementation costs can facilitate adoption in financially constrained regions. A significant challenge is field problems, as discussed by Izumi *et al.* [23], where incorrect data in broadcasters' transport streams lead to malfunctioning receivers. Their study highlights that many field problems arise from random errors in data structures and protocols, often not accounted for in standard testing environments. This indicates a need for robust, fuzzing-based test methodologies to ensure receivers can handle real-world errors and enhance reliability. These strategies can be complemented by training programs and local partnerships, as suggested by Oliveira *et al.* [12], to educate developers and content creators about Ginga's capabilities and benefits.

3) What has been the impact of Ginga extensions, such as IoT and multimedia applications, on user experience?: The extensions of Ginga for IoT and multimedia have enriched the user experience by providing greater interactivity and richer functionalities. In De Farias *et al.* [3], integration with IoT allows users to interact with home devices through the TV, increasing the usefulness of the digital TV system. Additionally, Junior *et al.* [4] highlights how improvements to

Ginga's performance and reliability through automated testing improve the user experience, reducing crashes and improving service quality. Ginga's evolution is further supported by updates to standards, which have enabled greater flexibility and interactivity, ensured efficient operation across a wide range of devices, and provided robust frameworks for high-quality multimedia support.

4) How have automatic content preparation techniques improved content delivery in digital TV systems?: Automatic content preparation has been crucial for improving synchronization, content retrieval, and delivery in digital TV systems. Ivanov *et al.* [8] illustrates how automatic preparation can reduce delays in rendering sensory effects, which is essential for maintaining the quality of the user experience. Additionally, these techniques streamline the content retrieval process, allowing for quick and efficient access to desired media. Complementarily, Josué *et al.* [21] explores how this technology enhances user experience by ensuring personalized content is delivered seamlessly, and optimizes targeted advertising delivery by dynamically adjusting ads based on viewer preferences and behavior, thereby increasing operational and commercial efficiency for broadcasters.

5) What are the current and future challenges for integrating sensory effects into digital TV broadcasts?: Integrating sensory effects into digital TV broadcasts presents technical and user experience challenges. As highlighted in Ivanov *et al.* [8], precise synchronization between audiovisual content and sensory effects is a significant technical challenge. Furthermore, De Paula *et al.* [6] shows that adapting sensory effects for specific audiences, such as the elderly, requires careful consideration of usability and accessibility. These challenges necessitate the continuous development of synchronization technologies and user interfaces that can adapt to the varied needs of users in different media contexts. In conclusion, this study provided a comprehensive view of the evolution of the Ginga middleware, highlighting its growing impact on digital TV interactivity and integration with emerging technologies such as IoT and multimedia applications. We identified significant challenges and opportunities in adopting Ginga in different regional contexts, emphasizing the importance of adaptive strategies that consider the cultural and economic peculiarities of each region. The extensions of Ginga, including automatic content preparation and IoT integration, proved vital in enriching the user experience, providing more dynamic and immersive interactivity. The implementation of sensory effects and the improvement of interactive service quality represent advances in how users interact with digital media, offering new possibilities for education, entertainment, and personal engagement.

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