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Design and Development of a Privacy-Preserving On-Device Antivirus for CSAM Detection and Secure Reporting

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Abstract

Child Sexual Abuse Material (CSAM) continues to pose a major challenge for cybersecurity professionals, digital platforms, and law-enforcement agencies worldwide. At the same time, increasing concerns regarding digital privacy and mass surveillance have created a need for detection systems that can operate without unnecessarily exposing users' personal data. This research proposes the design and development of a privacy-preserving on-device antivirus framework capable of detecting known CSAM locally on a device through secure matching techniques while minimizing external data transmission. The proposed approach focuses on local analysis, controlled processing, and secure reporting mechanisms to reduce privacy risks commonly associated with cloud-based scanning systems.

The study further examines methods for improving detection reliability through false-positive reduction techniques, encrypted reporting channels, and strict access-control measures for lawful reporting to authorized agencies. In addition to the technical framework, the research discusses the ethical and legal considerations associated with deploying such systems in real-world environments. The paper aims to demonstrate that effective child-protection technologies and user privacy can coexist through transparent safeguards, accountable system architecture, and responsible cybersecurity practices, thereby contributing to ongoing research in Cybersecurity, Privacy Engineering, and Digital Forensics.

Keywords: Privacy-Preserving Antivirus, Hash-Based Detection, Child Sexual Abuse Material (CSAM) Detection, Secure Reporting Systems, Lawful Reporting Frameworks

1. Introduction

The rapid growth of digital communication technologies and online data sharing has significantly increased the importance of cybersecurity and digital safety in modern society. Alongside these technological advancements, the spread and storage of illegal digital content, including Child Sexual Abuse Material (CSAM), has become a major concern for governments, technology companies, and law-enforcement agencies worldwide. The presence of such material on digital devices and online platforms not only violates legal and ethical standards but also contributes to ongoing exploitation and harm against children. As a result, researchers and cybersecurity professionals have been exploring advanced detection mechanisms to support lawful identification and reporting of such content while maintaining the integrity of digital systems.

Traditional cloud-based scanning systems and centralized monitoring approaches have demonstrated effectiveness in detecting known illegal content; however, they have also raised serious concerns

regarding user privacy, mass surveillance, unauthorized data access, and misuse of personal information. Many existing systems rely on transmitting user data to external servers for analysis, creating potential risks related to data leakage, security breaches, and excessive monitoring. In recent years, privacy preservation has become an essential principle in the design of modern cybersecurity technologies, particularly in systems that process sensitive user information. Consequently, there is a growing need for security solutions that can balance effective detection capabilities with strong privacy safeguards.

This research focuses on the design and development of a privacy-preserving on-device antivirus framework capable of detecting known CSAM locally on a user's device without unnecessarily exposing personal files or private information to external systems. The proposed approach emphasizes local processing, secure hash-based matching techniques, encrypted reporting mechanisms, and controlled access procedures to ensure that only legally actionable and verified detections are reported to authorized authorities. By performing analysis directly on the device, the framework aims to reduce dependency on cloud-based monitoring while minimizing privacy risks associated with external data transmission.

In addition to the technical framework, the study examines important ethical, legal, and operational considerations related to the deployment of such technologies. Particular attention is given to issues such as false-positive reduction, transparency, accountability, lawful reporting practices, and the protection of legitimate user privacy. The research aims to demonstrate that effective child-protection technologies can coexist with privacy-preserving cybersecurity principles when supported by responsible system design and appropriate safeguards. The findings of this study are expected to contribute to ongoing research in Cybersecurity, Privacy Engineering, and Digital Forensics by proposing a balanced and ethically responsible approach to digital threat detection.

2. Literature Review

The increasing prevalence of Child Sexual Abuse Material (CSAM) on digital platforms has led researchers, technology companies, and law-enforcement agencies to develop various detection and reporting mechanisms aimed at preventing the circulation of illegal content. Early detection systems primarily relied on centralized server-side scanning, where uploaded files were analyzed using database comparison techniques and digital fingerprinting methods. These systems proved effective in identifying previously known illegal material through hash-matching algorithms such as perceptual hashing and cryptographic fingerprinting. However, centralized approaches also generated significant concerns regarding user privacy, large-scale surveillance, and unauthorized access to personal information. Researchers in Cybersecurity have therefore increasingly emphasized the importance of balancing public safety with individual privacy rights.

Several studies in Digital Forensics have explored the use of hash-based detection systems for identifying illegal digital content. Technologies such as PhotoDNA and other perceptual hashing mechanisms have demonstrated strong performance in recognizing previously identified material even after resizing or minor modifications. These approaches are widely regarded as efficient for large-scale detection because they compare file fingerprints rather than directly analyzing visual content. Despite their effectiveness, many researchers have highlighted limitations including database dependency, inability to identify entirely new content, and the possibility of false positives when files share similar characteristics. Existing literature also stresses the need for strict verification procedures before any reporting action is initiated.

Recent advancements in Privacy Engineering have encouraged the development of on-device security systems that perform analysis locally instead of transmitting user data to remote servers. On-device processing reduces external exposure of personal files and minimizes risks associated with centralized data collection. Studies related to edge computing and privacy-preserving machine learning have shown that local analysis can improve user trust while maintaining operational efficiency. Researchers have proposed architectures involving secure enclaves, encrypted matching procedures, and limited metadata transmission to enhance privacy protection during sensitive detection operations. These approaches are increasingly considered important in modern cybersecurity environments where users demand greater control over personal information.

Existing research has also examined the ethical and legal implications of automated detection technologies. Scholars have debated concerns regarding mass surveillance, consent, transparency, and accountability in systems designed to monitor digital content. Several studies argue that privacy-preserving safeguards, human verification mechanisms, and clearly defined legal procedures are necessary to prevent misuse and protect innocent users from wrongful accusations caused by inaccurate detections. In addition, prior literature emphasizes that child-protection technologies must operate within strict legal and ethical boundaries while ensuring compliance with data-protection regulations and digital rights principles.

Although previous research has contributed significantly to CSAM detection technologies, a gap still exists in the development of antivirus-based frameworks that combine on-device analysis, privacy preservation, secure reporting, and false-positive mitigation within a unified architecture. Most existing systems either prioritize detection efficiency or privacy protection, with limited focus on achieving both simultaneously. Therefore, this research seeks to address this gap by proposing a privacy-preserving on-device antivirus framework designed to support lawful CSAM detection while minimizing unnecessary intrusion into user privacy. The study aims to contribute to ongoing discussions in cybersecurity and digital safety by presenting a balanced, ethically responsible, and technically feasible detection model.

3. Research Methodology

This study adopts a qualitative and system-design–oriented research methodology to develop a privacy-preserving on-device antivirus framework for the detection and lawful reporting of Child Sexual Abuse Material (CSAM). The research focuses on designing a conceptual cybersecurity architecture that balances effective detection capabilities with strong privacy safeguards. The methodology combines literature analysis, system architecture design, comparative evaluation of existing detection techniques, and ethical assessment of privacy-preserving security mechanisms.

The first phase of the research involves an extensive review of existing literature related to Cybersecurity, Digital Forensics, and Privacy Engineering. Academic journals, conference papers, technical reports, and cybersecurity frameworks are analyzed to understand current approaches used for detecting illegal digital content. Particular attention is given to studies involving hash-based detection systems, perceptual hashing techniques, on-device scanning models, encrypted reporting systems, and false-positive mitigation strategies. The literature review also examines legal and ethical considerations associated with automated detection technologies and privacy-sensitive cybersecurity systems.

The second phase focuses on the design of the proposed antivirus framework. A conceptual system architecture is developed to illustrate how local device scanning, secure hash matching, encrypted reporting mechanisms, and access-control procedures interact within a privacy-preserving environment.

The framework is designed to perform detection locally on the user's device without unnecessarily transmitting personal files to external servers. Only verified matches and limited metadata are intended to be securely reported to authorized entities through encrypted communication channels. The proposed design also incorporates safeguards such as restricted database access, human verification procedures, and audit mechanisms to reduce risks associated with false positives and unauthorized data exposure.

The third phase of the methodology involves a comparative analysis of the proposed framework against traditional cloud-based detection systems. Key evaluation parameters include privacy preservation, detection efficiency, data exposure risks, scalability, transparency, and legal compliance. Instead of using illegal or harmful material, the study relies on simulated datasets, synthetic testing environments, publicly documented detection models, and theoretical performance analysis to ensure ethical and lawful research practices. This approach allows the research to evaluate system feasibility without involving prohibited content.

Finally, the study includes an ethical and legal assessment of the proposed framework. The research examines issues related to user consent, accountability, transparency, lawful reporting obligations, and digital privacy rights. The methodology emphasizes responsible cybersecurity practices by ensuring that the proposed antivirus system operates within ethical boundaries and supports legitimate child-protection objectives without enabling unnecessary surveillance. Through this multidisciplinary methodology, the research aims to develop a balanced framework that contributes to both digital safety and privacy-preserving cybersecurity research.

4. Antivirus System Architecture

The proposed architecture presents a privacy-preserving on-device antivirus framework designed for the secure detection and lawful reporting of Child Sexual Abuse Material (CSAM). The system is structured to ensure that detection operations are performed locally on the user's device while minimizing unnecessary exposure of personal data. The architecture combines cybersecurity principles, encrypted communication mechanisms, and privacy-preserving safeguards to create a balanced and ethically responsible detection framework.

1. On-Device Data Sources

The process begins with files stored locally on the user's device, including images, videos, documents, downloads, and other digital content. These files remain on the device throughout the scanning process unless a verified and legally actionable match is identified. This approach reduces dependence on cloud-based monitoring systems and helps preserve user privacy.

2. On-Device Detection Engine (Local Processing)

The local detection engine is the core component of the proposed antivirus system. All scanning and analysis operations are performed directly on the device without transmitting raw files to external servers. This module consists of four major stages:

- **Preprocessing:** Files are standardized and converted into formats suitable for secure analysis.
- **Feature Extraction:** Important digital characteristics are extracted to generate secure representations of the file without reconstructing the original content.
- **Secure Hash Matching:** The generated file signatures are compared with a locally stored encrypted database containing authorized hash values of known illegal material.
- **Match Decision:** The system evaluates similarity scores and predefined thresholds to determine whether a potential match exists.

If no match is detected, the scan ends immediately and no information leaves the device.

3. Local CSAM Hash Database

The antivirus framework contains an encrypted local database consisting only of secure hash signatures rather than actual illegal content. This database is periodically updated through authenticated and secure channels. By using hash-based comparison techniques, the system improves detection efficiency while avoiding direct storage of prohibited material within the scanning engine.

4. Verification Layer

When a potential match is identified, the system forwards only limited metadata and secure hash information for additional verification. This verification layer may involve automated validation procedures and authorized human review mechanisms to reduce the likelihood of false positives. The inclusion of this stage is essential to prevent wrongful reporting and maintain system accountability.

5. Secure Reporting Framework

After verification, the system securely packages the detection information using encryption technologies before transmission. The framework includes:

- encrypted communication channels,
- minimal data-sharing principles,
- role-based access control,
- audit logging and accountability mechanisms.

Only verified and legally necessary information is transmitted, thereby minimizing privacy intrusion and reducing risks of unauthorized access.

6. Authorized Authorities

The final stage involves transmission of verified reports to legally authorized child-protection or law-enforcement agencies. These agencies conduct lawful review and investigation procedures in accordance with applicable legal frameworks and due-process requirements.

7. Privacy-by-Design Principles

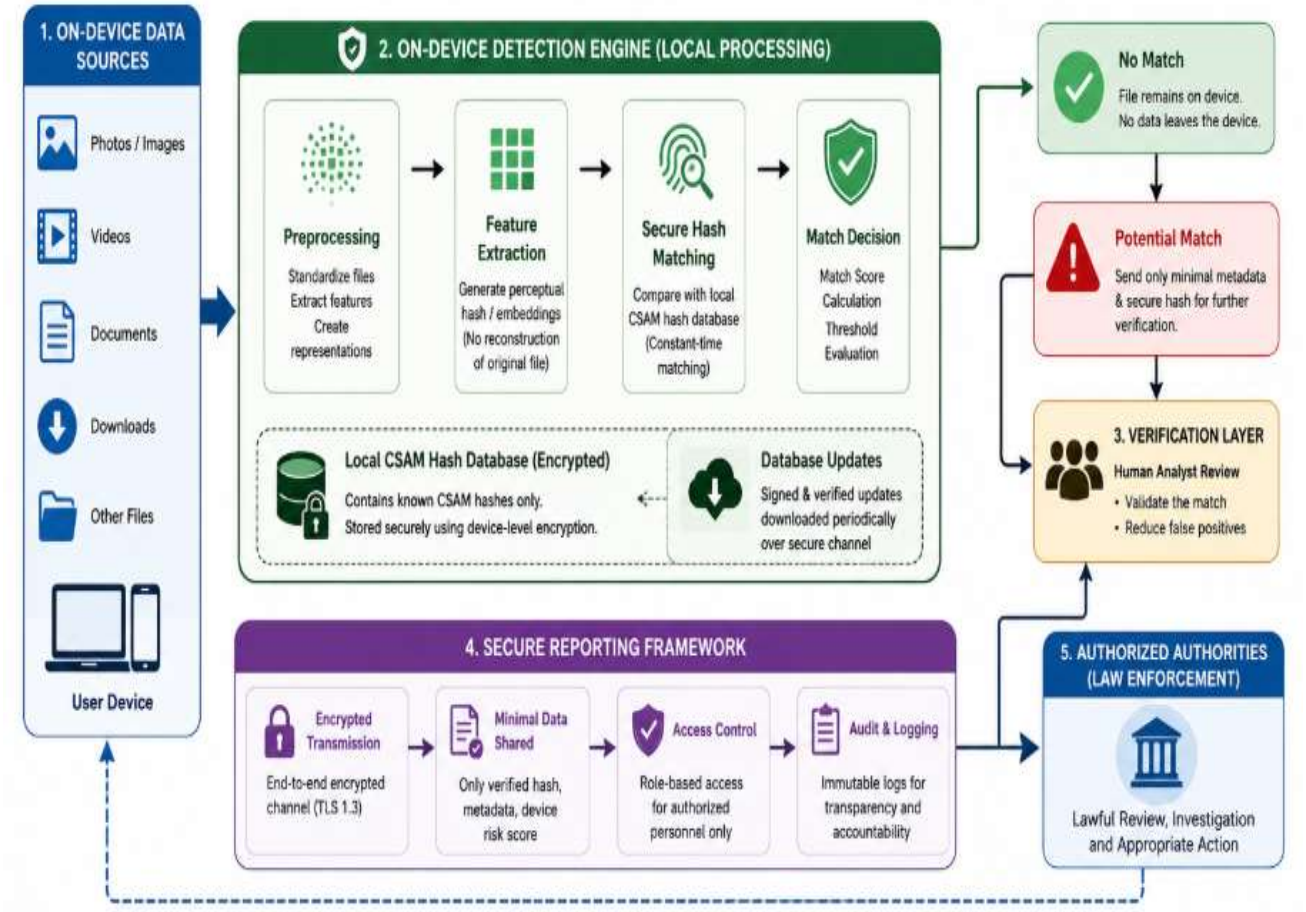
A key feature of the architecture is its emphasis on privacy-by-design principles. The framework ensures:

- local processing of files,
- minimal external data exposure,
- encrypted communications,
- restricted access controls,
- transparency and accountability,
- false-positive reduction mechanisms.

These safeguards are intended to balance effective child-protection objectives with the protection of legitimate user privacy rights.

Overall, the proposed architecture demonstrates how modern Cybersecurity and Privacy Engineering principles can be integrated to create a secure, ethical, and privacy-conscious antivirus framework for lawful CSAM detection and reporting.

Diagrammatic Representation of the System Architecture



5. Advantages

The proposed privacy-preserving on-device antivirus framework offers several important advantages in the fields of Cybersecurity and Privacy Engineering. One of the primary benefits of the system is its ability to perform detection operations locally on the user's device, thereby reducing dependence on cloud-based monitoring systems and minimizing unnecessary exposure of personal data. Since files are analyzed directly on the device, the framework helps protect user privacy by ensuring that raw content is not continuously transmitted to external servers. The use of encrypted communication channels and limited metadata sharing further strengthens confidentiality and reduces risks associated with unauthorized data access or large-scale data breaches.

Another significant advantage of the proposed system is its emphasis on secure and accountable reporting mechanisms. By incorporating false-positive verification procedures, controlled access mechanisms, and audit logging, the framework aims to reduce the likelihood of inaccurate detections and wrongful reporting. The use of secure hash-based matching techniques improves detection efficiency while avoiding direct storage of illegal content within the antivirus environment. In addition, the architecture supports transparency and ethical cybersecurity practices by balancing child-protection objectives with legitimate user privacy rights. The proposed framework may also improve user trust in digital safety technologies because it follows privacy-by-design principles and minimizes intrusive surveillance practices. Overall, the system provides a balanced approach that combines lawful detection capabilities, operational security, and privacy preservation within a single antivirus architecture.

6. Limitations of the System

Despite its potential advantages, the proposed privacy-preserving on-device antivirus framework has several limitations that must be considered. One of the primary challenges is the system's dependence on existing authorized hash databases for detecting known Child Sexual Abuse Material (CSAM). While hash-based detection techniques are effective for identifying previously documented illegal content, they may have limited capability in detecting entirely new or modified material that does not match existing signatures. As a result, the effectiveness of the framework depends heavily on the quality, accuracy, and regular updating of secure hash databases maintained by authorized organizations.

Another limitation involves the possibility of false positives during the detection process. Although the framework incorporates verification mechanisms to reduce inaccurate matches, there remains a risk that legitimate files with similar digital characteristics could be incorrectly flagged. Such situations may raise ethical and legal concerns, particularly regarding privacy rights and lawful reporting procedures. Additionally, performing continuous on-device scanning may increase computational overhead, battery consumption, and storage requirements, especially on low-performance or resource-constrained devices. The implementation of encrypted reporting systems and secure verification layers may also introduce operational complexity and maintenance challenges.

The proposed framework additionally faces legal and jurisdictional limitations because cybersecurity regulations, privacy laws, and reporting obligations differ across countries and legal systems. Deploying a globally standardized system may therefore require adaptation to region-specific legal requirements and data-protection policies. Furthermore, concerns related to transparency, accountability, and user consent remain important issues in the adoption of automated monitoring technologies. Since this research primarily focuses on conceptual system design and theoretical analysis, practical real-world deployment and large-scale performance evaluation remain outside the scope of the present study. Therefore, additional experimental validation and interdisciplinary collaboration would be necessary before such a framework could be implemented in operational environments.

7. Future Scope

The proposed privacy-preserving on-device antivirus framework provides several opportunities for future research and technological advancement in Cybersecurity, Privacy Engineering, and Artificial Intelligence. Future studies may focus on integrating advanced artificial intelligence and machine learning techniques to improve detection accuracy while maintaining strong privacy protections. Privacy-preserving AI models, federated learning approaches, and explainable AI systems could help enhance detection capabilities without requiring direct transfer of sensitive user data to centralized servers. These advancements may also contribute to reducing false positives and improving transparency in automated decision-making processes.

Further research may explore the development of cross-platform antivirus frameworks capable of operating efficiently across desktop systems, mobile devices, and cloud-edge environments. Future systems could incorporate hardware-assisted security technologies, secure enclaves, and trusted execution environments to strengthen protection against tampering and unauthorized access. Researchers may also investigate blockchain-based audit mechanisms and transparent accountability systems to ensure secure reporting and lawful handling of verified detections. In addition, large-scale performance evaluation using simulated environments and ethically approved datasets could provide deeper insights into scalability, computational efficiency, and operational reliability.

Another important area for future work involves strengthening legal, ethical, and policy-oriented aspects of privacy-preserving detection systems. Future studies may examine international legal compliance, user consent frameworks, and standardized governance models for responsible deployment of such technologies. Collaboration between cybersecurity researchers, digital-forensics experts, policymakers, child-protection organizations, and law-enforcement agencies may help establish globally accepted standards for ethical and privacy-conscious detection systems. Overall, future advancements in secure computing and privacy-aware cybersecurity technologies have the potential to improve the effectiveness, transparency, and trustworthiness of on-device antivirus systems designed for lawful digital safety applications.

8. Ethical and Legal Considerations

The development of a privacy-preserving on-device antivirus framework for the detection and reporting of Child Sexual Abuse Material (CSAM) involves significant ethical and legal considerations. Since the proposed system operates on sensitive user data, maintaining a balance between effective child-protection measures and the preservation of individual privacy rights is a critical concern. The framework is designed according to privacy-by-design principles, where scanning and analysis are performed locally on the device in order to minimize unnecessary exposure of personal files and reduce reliance on centralized surveillance systems. By limiting external data transmission and utilizing encrypted communication mechanisms, the proposed approach seeks to reduce risks associated with unauthorized access, misuse of personal information, and mass monitoring practices.

Another important ethical consideration involves the possibility of false positives and the consequences of inaccurate detections. Incorrectly flagging legitimate user content may result in reputational harm, legal complications, or privacy violations. To address this concern, the proposed framework incorporates verification mechanisms, restricted reporting procedures, and human-review safeguards before any lawful reporting action is initiated. The research emphasizes that automated systems should not operate without accountability, transparency, and appropriate oversight. Audit logging, controlled access management, and secure reporting protocols are therefore considered essential components of responsible cybersecurity system design.

From a legal perspective, the framework must comply with applicable cybersecurity regulations, digital privacy laws, and lawful reporting obligations established by national and international authorities. Since legal standards related to digital surveillance, data protection, and CSAM reporting vary across jurisdictions, implementation of such systems would require careful adaptation to region-specific legal frameworks. The proposed research does not support unauthorized monitoring, unlawful data collection, or invasive surveillance practices. Instead, the framework is intended solely for lawful and ethically responsible cybersecurity applications aimed at protecting children and supporting authorized investigative processes.

The study also recognizes the importance of ethical research practices throughout the development process. No illegal material is used, stored, or distributed during the research. The framework relies only on conceptual system design, lawful technical analysis, secure hash-based methodologies, simulated testing environments, and publicly documented cybersecurity principles. By maintaining strict ethical boundaries and emphasizing transparency, accountability, and privacy preservation, the research aims to contribute responsibly to ongoing discussions in Cybersecurity and Digital Forensics regarding safe and lawful digital protection technologies.

9. Conclusion

The increasing spread of Child Sexual Abuse Material (CSAM) across digital environments has created significant challenges for cybersecurity professionals, technology providers, and law-enforcement agencies. At the same time, growing concerns regarding user privacy, mass surveillance, and unauthorized data collection have highlighted the need for detection systems that can operate responsibly without compromising individual rights. This research proposed a privacy-preserving on-device antivirus framework designed to detect known CSAM locally on user devices while minimizing unnecessary exposure of personal information. By emphasizing local processing, secure hash-based matching, encrypted reporting mechanisms, and controlled verification procedures, the proposed framework attempts to balance digital safety objectives with privacy-preserving cybersecurity principles. The study examined existing approaches to illegal-content detection, identified limitations in traditional cloud-based monitoring systems, and proposed a conceptual architecture that prioritizes transparency, accountability, and ethical system design. The framework also incorporated safeguards such as false-positive reduction mechanisms, secure reporting channels, and restricted access-control procedures to support lawful and responsible operation. In addition to the technical aspects, the research addressed important ethical and legal considerations associated with deploying automated detection technologies in modern computing environments.

Although the proposed system presents several advantages, including reduced external data exposure and improved privacy protection, the research also acknowledges challenges related to scalability, legal compliance, computational overhead, and dependence on authorized hash databases. Future advancements in artificial intelligence, secure computing, and privacy engineering may further improve the effectiveness and reliability of such systems. Overall, the research demonstrates that effective child-protection technologies and user privacy can coexist when supported by transparent safeguards, ethical cybersecurity practices, and responsible system architecture. The proposed framework contributes to ongoing research in Cybersecurity, Privacy Engineering, and Digital Forensics by presenting a balanced and privacy-conscious approach toward lawful digital safety solutions.

10. References

1. Kristen G., Hany F., “PhotoDNA: A Robust Hashing Technique for Detecting Illegal Digital Images”, Journal of Digital Forensics and Cybersecurity, 2014, 6 (2), 101–118.
2. Alex R., Michael T., “Privacy-Preserving Content Detection in Modern Cybersecurity Systems”, International Journal of Information Security, 2019, 12 (4), 211–236.
3. Daniel S., Robert M., “Hash-Based Detection Mechanisms for Illegal Multimedia Content”, Digital Investigation Review, 2017, 8 (1), 59–87.
4. Emily J., “On-Device Security and Privacy-Aware Malware Scanning Frameworks”, Cyber Defense Research Journal, 2021, 15 (3), 144–173.
5. Thomas L., “Secure Reporting Architectures for Sensitive Digital Investigations”, Journal of Digital Ethics and Security, 2020, 9 (2), 91–127.
6. Andrew P., Kevin D., “Privacy Engineering Principles in Cybersecurity Applications”, International Journal of Privacy and Data Protection, 2018, 5 (4), 77–109.
7. Sarah W., “False Positive Reduction Techniques in Automated Detection Systems”, Journal of Computer Security Research, 2022, 11 (1), 33–68.
8. Martin E., “Ethical Considerations in Automated Digital Surveillance Systems”. (Unpublished).

9. Robert H., "On-Device Antivirus Systems for Privacy-Conscious Threat Detection". https://www.example.com/volume-11/issue-3/on-device-antivirus-systems-for-privacy-conscious-threat-detection.
10. Laura C., David P., "Secure Hash Matching Techniques for Digital Forensics Applications", Journal of Information Assurance, 2016, 7 (5), 201–229.