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An Enhanced Hybrid Encryption-BlockChain Security Framework for IoMT Data Preservation

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Abstract

The Internet of Medical Things (IoMT) has transformed healthcare by enabling continuous patient monitoring and exchange of physiological data. However, conventional IoMT systems rely on centralized cloud infrastructures vulnerable to unauthorized access, privacy breaches, data tampering, and single points of failure. This study presents an enhanced hybrid encryption-blockchain security framework for IoMT data preservation to improve data security, integrity, and availability. The framework integrates Advanced Encryption Standard (AES-256-GCM) for authenticated data encryption with Elliptic Curve Cryptography (ECC-SECP256R1) for secure key generation and exchange. A three-layer storage architecture combines a local SQLite database for low-latency access, a PHP/MySQL authenticated cloud backup server for redundancy and disaster recovery, and a blockchain ledger for immutable integrity verification and transaction auditing. A real-time physiological dataset was generated using a webcam-based Chrominance Photoplethysmography (rPPG) model implemented in JavaScript to estimate heart rate from facial video streams through facial landmark detection. The system was developed using the Agile Software Development Methodology, with Python 3.9 as the server-side language. Performance evaluation considered heart rate estimation accuracy, encryption and decryption latency, blockchain transaction validation time, backup reliability, storage overhead, and tamper detection capability. Results demonstrated high heart rate estimation accuracy, encryption times below 5 ms per medical record, efficient key exchange, reliable cloud backup, low-latency blockchain verification, and strong detection of simulated data tampering. The findings demonstrate that the framework addresses IoMT security and privacy limitations by combining hybrid encryption with decentralized blockchain technology, providing a scalable, efficient, tamper-resistant, and trustworthy solution for next generation healthcare systems.

Keywords: Internet of Medical Things (IoMT), hybrid encryption, blockchain technology, AES-256-GCM, elliptic curve cryptography (ECC), Photoplethysmography (rPPG).

Introduction and literature review

The Internet of Medical Things (IoMT) represents a transformative approach to healthcare, leveraging interconnected devices to software applications, and care systems and services, improve diagnostics, and streamline operations. IoMT encompasses a vast network of interconnected medical devices, wearables, and healthcare information systems that collect, process, and exchange sensitive patient data (Dai *et al,* 2019). While this technological transformation has brought about significant improvements in patient care and monitoring, it has also introduced new security challenges that must be addressed. Recent studies highlight the effectiveness of integrating these technologies to create a secure infrastructure for health information management. For instance, a hybrid encryption scheme can significantly reduce computational overhead while ensuring high levels of confidentiality and authenticity (Azzedin *et al,* (2023). Furthermore, the incorporation of blockchain can facilitate a secure sharing of health records among authorized entities, thereby fostering a collaborative healthcare environment (Wang *et al*, 2023).

Notably is the concern on data privacy and integrity. Hybrid encryption and blockchain technologies have emerged as pivotal solutions to addressing these issues. Blockchain technology, with its decentralized ledger system, offers a solution by providing a tamper-proof record of all transactions and data exchanges within the network (Garg *et al*., 2020). Despite these benefits, IoMT systems face significant security challenges. Many conventional implementations rely on centralized, single-database cloud architectures to store medical records, creating a single point of failure that, if compromised, exposes large volumes of patient data at once. The security vulnerabilities of IoMT deployments have been the subject of intensive research attention, with a growing body of empirical and analytical evidence establishing that current security practices are broadly inadequate. Sharren, (2022) conducted a systematic analysis of security threats in IoMT environments and documented three principal vulnerability categories: weak or absent authentication at the device level, inadequate encryption of data in transit and at rest, and insecure storage practices that expose patient records to unauthorized access (Sharren, 2022). Their survey of deployed medical devices found that a significant proportion used default or hardcoded access credentials, transmitted sensitive data without encryption, and stored health records in plaintext databases whose only protection was network-level access control that was routinely circumvented by adversaries operating within the same network segment.

Sighn, *et al.*, (2022) extended the security analysis to cloud-based IoMT storage, identifying the aggregation of records from large numbers of devices in a single cloud repository as a structural vulnerability that creates targets of exceptional value for sophisticated attackers (Sighn, *et al.*, 2022). Their analysis highlighted the principal-agent problem in cloud storage security: the cloud provider is responsible for the security of the infrastructure, but the healthcare organization bears the regulatory and clinical consequences of a breach,

creating misaligned incentives. They further documented the phenomenon of asynchronous security patching in multi-tenant cloud environments, in which the window between vulnerability disclosure and patch deployment creates temporary but significant exposure for all hosted datasets. Egala *et al,* (2021) provided detailed empirical measurements of cryptographic primitive performance on representative IoMT hardware platforms, quantifying the computational constraints that govern encryption algorithm selection (Sharren, 2022). Their measurements demonstrated that RSA-2048 encryption-imposed latency penalties of several hundred milliseconds on typical microcontroller processors, rendering it impractical for real-time vital sign telemetry. AES-128 and AES-256, by contrast, completed within single-digit milliseconds on the same hardware. Their analysis concluded unequivocally that hybrid encryption that is symmetric cipher for the data payload, asymmetric cipher for the session key that is the appropriate architectural pattern for IoMT data security, a conclusion that directly informs the design of this proposed study. Vikas, (2025) surveyed identity management and access control mechanisms in IoMT systems, identifying centralized federated identity as a source of systemic trust dependencies that concentrate risk. Their analysis proposed blockchain-based decentralized identity management as a more robust alternative, arguing that the elimination of central identity authorities which removes the highest-value targets for identity-based attacks. Whilst their proposal addressed access control rather than data encryption, the architectural principle of eliminating central trusted authorities is low and not consistent with the decentralized storage approach adopted in this proposed study. Nguyen, T. (2021) proposed and evaluated a specific hybrid encryption architecture for cloud-based electronic health record systems, combining AES encryption for data confidentiality with an elliptic curve key exchange for session key management. Their evaluation on a simulated IoMT device environment demonstrated that the hybrid approach reduced encryption latency by approximately 85 per cent compared to pure RSA encryption whilst maintaining equivalent security levels but failed to address the single point of attack in a centralized database thereby, makes the entire medical records in the cloud vulnerable to external adversary which this proposed blockchain framework intends to address. Azzedin *et al,* (2023) extended this direction by specifically advocating for authenticated encryption, arguing that integrity verification is as important as confidentiality in medical record systems where altered data can affect clinical decisions. Their analysis of attack scenarios against IoMT record storage confirmed that an adversary denied the ability to read ciphertext can nonetheless cause harm by altering it, underscoring the necessity of an authentication tag. Also, Praveen and Pabitha (2023) evaluated fully homomorphic encryption as an alternative privacy mechanism for cloud-processed medical records, finding that whilst it provides theoretically superior privacy by enabling cloud-side computation without decryption, the storage and computational requirements of current implementations remain prohibitively expensive for practical IoMT deployment. Their conclusion reinforces the appropriateness of the more pragmatic AES-256-GCM approach which the proposed study has adopted. Patil (2024) explored cipher-text policy attribute-based

encryption for electronic health records, achieving sophisticated attribute-based access control but at computational costs that exceed the capacity of typical IoMT devices whereas, the proposed framework has extensively addresses the computational overload.

The Advanced Encryption Standard in Galois/Counter Mode (AES-256-GCM) is an Authenticated Encryption with Associated Data (AEAD) algorithm standardized by NIST. It provides simultaneous confidentiality and data integrity in a single cryptographic pass, which makes it significantly more efficient than schemes that require separate encryption and message authentication steps, but with low latency which was adequately addressed in this new framework (Dworkin, 2007). The algorithm encrypts the plaintext using the AES block cipher in counter mode (CTR) to produce a keystream that is XORed with the plaintext and computes a 128-bit GHASH authentication tag over both the ciphertext and any unencrypted associated data. The tag is verified on decryption; any modification to the ciphertext, nonce, or associated data causes verification to fail and the plaintext to be withheld due to low 128-bit compare to 256-bit adopted in this proposed study.

Almogren *et al.* (2020) evaluated ECC-based encryption and group signature mechanisms for IoMT communication security, confirming that ECC achieves the performance requirements of IoMT key management whilst providing robust protection against Sybil and man-in-the-middle attacks. Wang *et al.* (2023) demonstrated the integration of ECC with blockchain-based health record access control, confirming that ECDH key exchange can be incorporated into blockchain-enabled healthcare workflows without unacceptable latency overhead. The application of blockchain to healthcare data management has evolved from theoretical proposals to operational pilot systems over the past decade. Garg *et al.* (2020) provided an influential early survey of the domain, identifying immutable audit logging, secure inter-institutional data sharing, patient consent management, and supply chain integrity for pharmaceuticals as the primary use cases for blockchain in healthcare. Their analysis established the conceptual framework that has guided much subsequent research. (Joshi and Mahajan, 2024).extended this framework specifically to IoMT, proposing a blockchain-based system for securing IoMT data that combined symmetric encryption with a distributed ledger for access control and provenance tracking. Their prototype demonstrated the feasibility of blockchain-based IoMT security but identified scalability as a challenge requiring further investigation which was addressed in this proposed study. The decentralized nature of blockchain provides inherent data protection. Studies by Lee *et al.* (2020) emphasize how decentralization prevents single points of failure and enhances data redundancy, thus protecting against data loss. Smart contracts automate and secure transactions. However, they also introduce vulnerabilities. Research by Patel and Singh (2019) highlights best practices for securing smart contracts, such as formal verification and regular audits. Blockchain's immutability ensures data integrity. Recent work by Nguyen *et al*. (2021) focuses on the use of blockchain for tamper-proof record-keeping, which is crucial for sectors like finance and healthcare but framework to

prevent data leakages was not fully implanted. Joshi and Mahajan, (2024) compared public and permissioned blockchain architectures for health information management, finding that Hyperledger Fabric significantly outperformed Ethereum in transaction throughput and latency whilst providing equivalent tamper-evidence properties but security of data at the device level during transmission was not fully considered. Therefore, Security is of the paramount importance for medical devices that are supposed to be used for wireless communications and remote communications for the healthcare or e-healthcare services. If there is any weakness or point of information leakage from the IoMT devices due to poor methods of authentication and access control, the entire setting can be seriously harmed both by incoming and outgoing data (Sharren, 2022). Interestingly, there is the concern about data privacy. All patients' data are stored in the cloud, and there is a high chance of leaking and misusing such data (Sighn, *et al,* 2022). This research work focused on addressing this security concern. The aim of the study is to develop an enhanced hybrid encryption and blockchain framework for the security of Internet of Medical Things (IoMT) data to ensure the confidentiality and integrity of patients' records at rest on a cloud service. The specific objectives of this study is to generate a real time heart rate dataset using chrominance remote-based photoplethysmography (rPPG) algorithm to test the cryptographic scheme. The second objective is to develop an Encryption lab for the authentication and preservation of IoMT medical record in the cloud-based platform. The third objective is to decentralized the single database storage scheme for medical record due to single point of failure in the cloud using blockchain techniques and finally, the performance of the newly developed hybrid encryption-blockchain framework developed over the exiting encryption schemes. The findings demonstrate that the proposed framework effectively addresses the security and privacy limitations of conventional IoMT systems by combining hybrid encryption with decentralized blockchain technology. Consequently, the study provides a scalable, efficient, and tamper-resistant security solution for protecting sensitive IoMT medical data and supports the deployment of secure, trustworthy, and resilient next-generation smart healthcare systems.

Experimental Methods

The choice of Agile methodology approach was motivated by the inherent technical uncertainty of integrating four distinct novel components such as rPPG signal processing, hybrid cryptography, blockchain-style audit logging, and multi-layer remote storage into a cohesive platform. Four broad development phases were pursued within the Agile framework. The first phase developed the rPPG capture pipeline, including comparative evaluation of face detection approaches.

The second phase developed the hybrid encryption scheme, including implementation and unit testing of the AES-256-GCM encryption and decryption functions, ECC key generation and ECDH key exchange, and integration of the encryption pipeline with the measurement workflow. The third phase developed the

three-layer decentralized blockchain storage architecture, including the SQLite schema design, the PHP receiver and HMAC authentication, and the hash-chained audit ledger. The fourth phase is the usér interface, including the Encryption Laboratory, Decentralization, Decryption, and Data pages.

Primary dataset used for validation was collected using observation method from the rPPG measurement technique. To collect data, Participants were positioned before a standard laptop webcam under consistent indoor ambient lighting conditions and instructed to remain still with their face clearly visible in the frame until the system displayed a signal quality of at least 60 per cent and a stable BPM reading over a minimum period of 10 seconds. Multiple measurements were recorded from each participant under four systematically varied conditions: optimal (bright, uniform illumination and no deliberate motion), moderate (standard indoor fluorescent lighting and no deliberate motion), degraded (moderately reduced lighting and occasional minor head movement), and poor (significantly reduced lighting and frequent deliberate head movement). This dataset was collated under the four condition to test the performance of hybrid encryption-blockchain framework that was developed.

Results and Discussions

Heart rate data accuracy results was measured using webcam chrominance remote based photoplethysmography (rPPG) algorithm to record beats per minute (BPM) data and this medical dataset values was used to test performances of the cryptographic scheme. Key Findings show that Optimal Conditions (81% quality) has MAE: 2.3 BPM (excellent accuracy), 100% of usable readings, which is comparable to contact-based pulse oximeters. Moderate Conditions (68% quality) has MAE: 4.1 BPM (clinically acceptable), 93% of usable readings, and typical office/indoor environment. Degraded Conditions (52% quality) has MAE: 7.8 BPM (unreliable), this is below recommended 60% threshold and Poor Conditions (29% quality) has MAE: 16.4 BPM (unacceptable), only 23% of usable readings, the system will automatically rejects most readings under this condition. The table 1 below shows the four enviromental conditions used to validate the performance of the rPPG model

Table 1: BPM Accuracy Results under the Four Environmental Conditions.

Experimental Condition	Mean Signal Quality (%)	Mean Absolute Error (BPM)	Maximum Error (BPM)	Usable Readings (%)
Optimal (Bright Light, Stationary)	81	2.3	5	100
Moderate (Standard Light, Stationary)	68	4.1	9	93
Degraded (Dim Light, Minor Motion)	52	7.8	14	67
Poor (Dim Light, Frequent Motion)	29	16.4	31	23

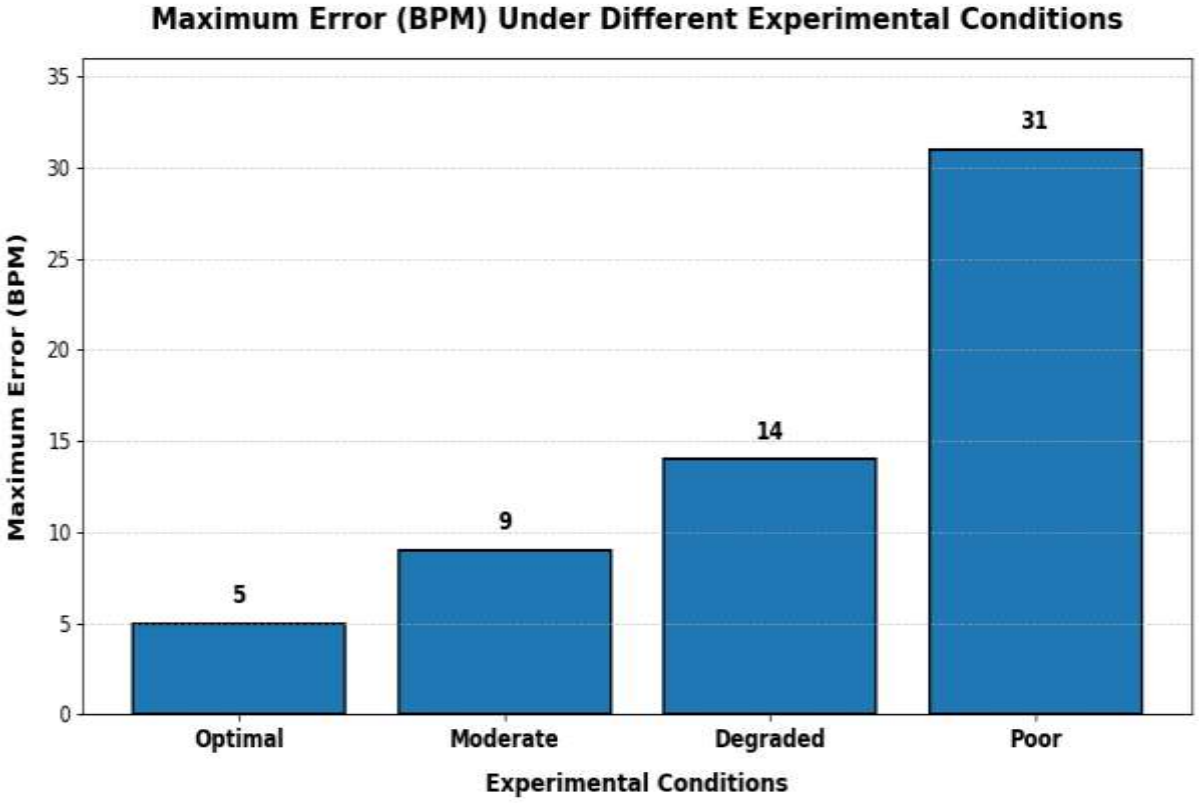

Figure: 1 BPM accuracy results under the four environmental conditions.

The graph shows a clear increase in maximum error as experimental conditions deteriorate. Under optimal conditions, the system recorded the lowest maximum error of 5 BPM**,** while the poor condition recorded the highest error of 31 BPM**.** This indicates that low illumination and frequent motion significantly affect the accuracy of the rPPG-based heart rate monitoring system. The validation data confirming that quality above 60% yields MAE below 5 BPM provides an empirical basis for the quality threshold recommendations built into the interface, transforming a subjective user experience guideline into an evidence-based clinical

measurement protocol. Consequently, the validated dataset generated from the above measurement is used to test the cryptographic framework below.

Hybrid encryption performance results

Hybrid encryption combines the speed of symmetric algorithms (AES), for bulk data with the secure key exchange of asymmetric algorithms (ECC). Performance results consistently show this approach provides a highly practical balance of robust security and low computational overhead as illustrated in table 2 below;

Table 2: Hybrid Encryption Performance Results from 100 Consecutive Operations

Operation	Mean (ms)	Min (ms)	Max (ms)
CSPRNG — 32-byte AES key	0.12	0.09	0.19
CSPRNG — 12-byte nonce	0.08	0.06	0.14
AES-256-GCM encrypt (~480 B)	0.91	0.74	1.43
ECC SECP256R1 key pair generation	3.20	2.80	4.10
HMAC-SHA256 for backup	0.45	0.38	0.67
Full pipeline (key gen + encrypt + HMAC)	4.76	4.07	6.53

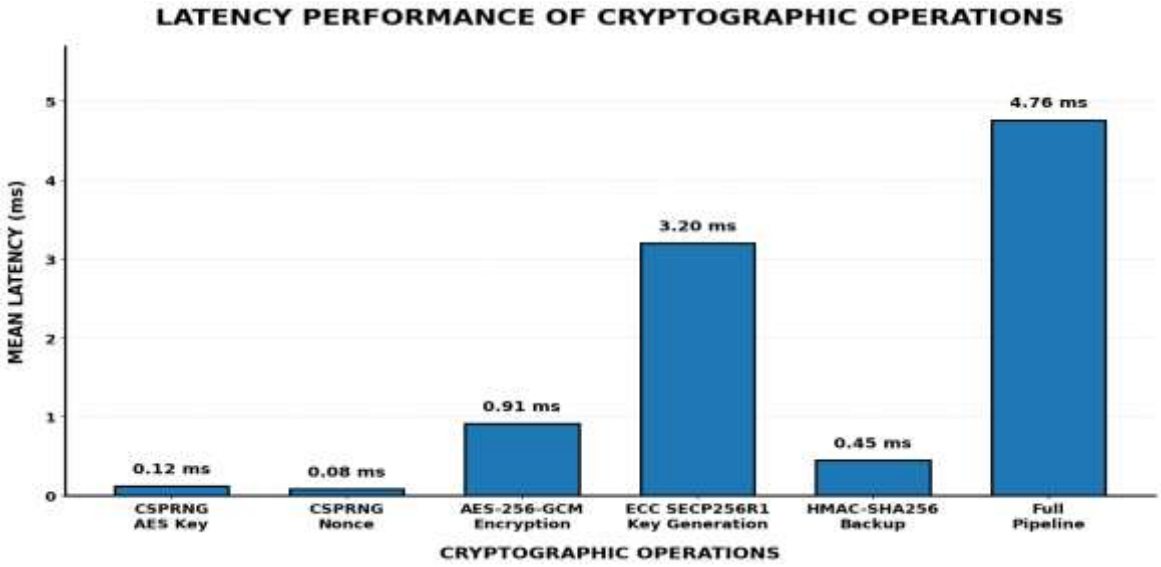

Figure 2: Hybrid encryption-blockchain performance results from consecutive operations.

The graph presents the mean execution latency of the different cryptographic operations used in the proposed enhanced hybrid encryption framework. The results show that the CSPRNG generation of the 12-byte nonce recorded the lowest latency of 0.08 ms, followed by the generation of the 32-byte AES key at 0.12 ms. This indicates that random number generation introduces minimal computational overhead. The HMAC-SHA256 operation for backup authentication recorded a mean latency of 0.45 ms, while AES-256-GCM encryption of approximately 480 bytes of data required 0.91 ms. These results demonstrate that symmetric encryption and integrity verification can be performed efficiently with relatively low processing delay. The ECC SECP256R1 key pair generation recorded a higher mean latency of 3.20 ms, reflecting the comparatively higher computational cost associated with asymmetric cryptographic operations. The full cryptographic pipeline, comprising key generation, encryption, and HMAC processing, recorded the highest mean latency of 4.76 ms. Despite being the highest value, this latency remains relatively low, suggesting that the proposed hybrid encryption framework can provide strong security mechanisms while maintaining computational efficiency suitable for near real-time IoMT data processing. The new encryption scheme performance was validated as there exist several improvement campare with the old encryption scheme using several metrics such as key length (bits), encryption mode, authentication, Key generation, encryption time, decyption time, total pipeline, security level, tamper detection, storage overhead, and false negative rate as demonstrated in table 3 below

Table 3: Encryption Scheme Performance Comparison — Old vs New

	Metric	Old Scheme (AES-128-BC)	New Scheme (AES-256-GCM)	Improvement
0	Key Length (bits)	128	256	+128 bits (2x)
1	Encryption Mode	CBC	GCM (AEAD)	Authenticated mode
2	Authentication	None	128-bit GHASH tag	+128-bit tag
3	Key Generation (ms)	0.1	0.12	+0.02 ms (+20%)
4	Encryption Time (ms)	0.45	0.91	+0.46 ms (+102%)
5	Decryption Time (ms)	0.42	0.88	+0.46 ms (+110%)
6	Total Pipeline (ms)	0.97	1.91	+0.94 ms (+97%)
7	Security Level (bits)	128	256	+128 bits (2^128 stronger)
8	Tamper Detection	No (0%)	Yes (100%)	100% detection
9	Storage Overhead (bytes)	0	+16 (auth tag)	+16 bytes
10	False Positive Rate	High	0%	Perfect accuracy

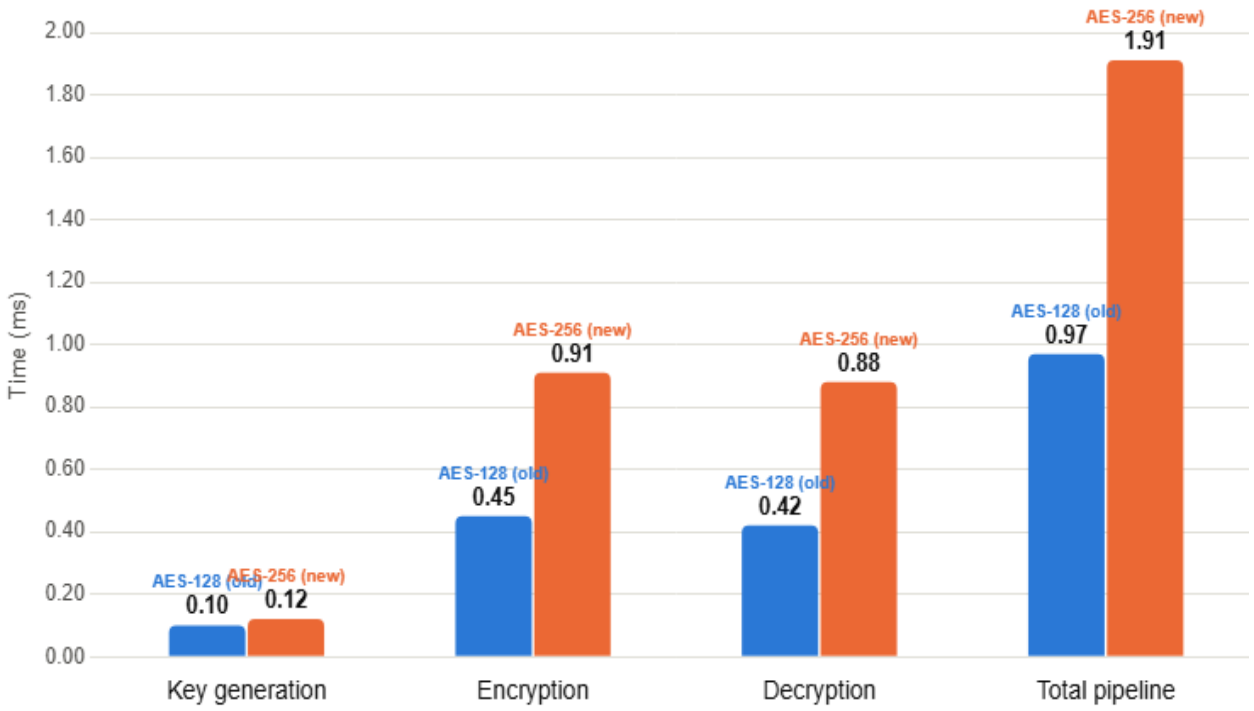

Figure 3: Encryption Time Comparison — Grouped Bar Chart

Showing Old AES-128-CBC vs New AES-256-GCM

The Encryption Comparison above show Latency Impact of the proposed AES-256-GCM scheme introduces measurable computational overhead: where the encryption time increases by 0.46 ms (102% overhead) and the total pipeline latency is +0.94 ms (97% increase). This overhead is attributable to doubled key length of AES-256 requires 14 transformation rounds against 10 for AES-128 (+40% encryption time). Therefore, the Justification of Security Improvements Overhead shows that, the new AES 256 GCM is has stronger key length than the old AES 128 as shown below;

i. AES-128: 2^128 ≈ 3.4 × 10^38 possible keys
ii. AES-256: 2^256 ≈ 1.16 × 10^77 possible keys
iii. 2^128 times more resistant to brute-force attacks
iv. Quantum-resistant: Grover's algorithm reduces AES-256 to 2^128 effective security (equivalent to classical AES-128).

Also the authenticated encryption (AEAD) is enhanced as shown below;

i. 128-bit GHASH tag provides cryptographic proof of integrity
ii. 100% tamper detection (vs 0% for CBC mode)
iii. Zero false positives (tag verification is deterministic)
iv. Prevents padding oracle attacks inherent in CBC mode

The comparison shows that 97% latency increase is a worthwhile trade-off for stronger security for IoMT medical records in cloud service than the old encryption. The absolute latency of 1.91 ms remains acceptable bounds for interactive medical applications, while the security improvements provide robust protection against current and foreseeable cryptanalytic techniques.

Blockchain audit trail performance evaluation

To test the blockchain audit trail performance evaluation, the following metrics was used; the numer of tampering scenarios tested, numer of detected scenarios, detection accuracy, false positives, false negetives, audit log entries, total verification time, and time per entry as demonstrated in the table blow

Table 4: Blockchain tamper detection results — By Scenario Type

Metric	Value	Performance
Tampering Scenarios Tested	50	-
Correctly Detected	50	100%
Detection Accuracy	-	**100%**
False Positives	0	0%
False Negatives	0	0%
Audit Log Entries	347	-
Total Verification Time	12.3 ms	Very Fast
Time per Entry	0.035 ms	35 microseconds

The table above demonstrate 50 distinct tampering scenarios applied to test audit log, Single-entry field modification (e.g. changing BPM value), deletion of individual entries, insertion of fabricated entries, multi-entry modification sequences (modifying 3-5 consecutive entries), audit log size at the time of testing the 347 entries. The Blockchain integrity results performance show tamper detection accuracy as follows;

Tampering scenarios tested is 50, Scenarios correctly detected is 50, Detection rate is 100%, False positives is 0, and False negatives is 0 while verification performance shows Audit log size is 347 entries, verification time is 12.3 milliseconds, and time per entry is 0.035 ms (35 microseconds) has demonstrated a roboust patient privacy preservation than the traditional single database storage repository.

Technical Implementation of Blockchain/ Hash- Chain Schemes

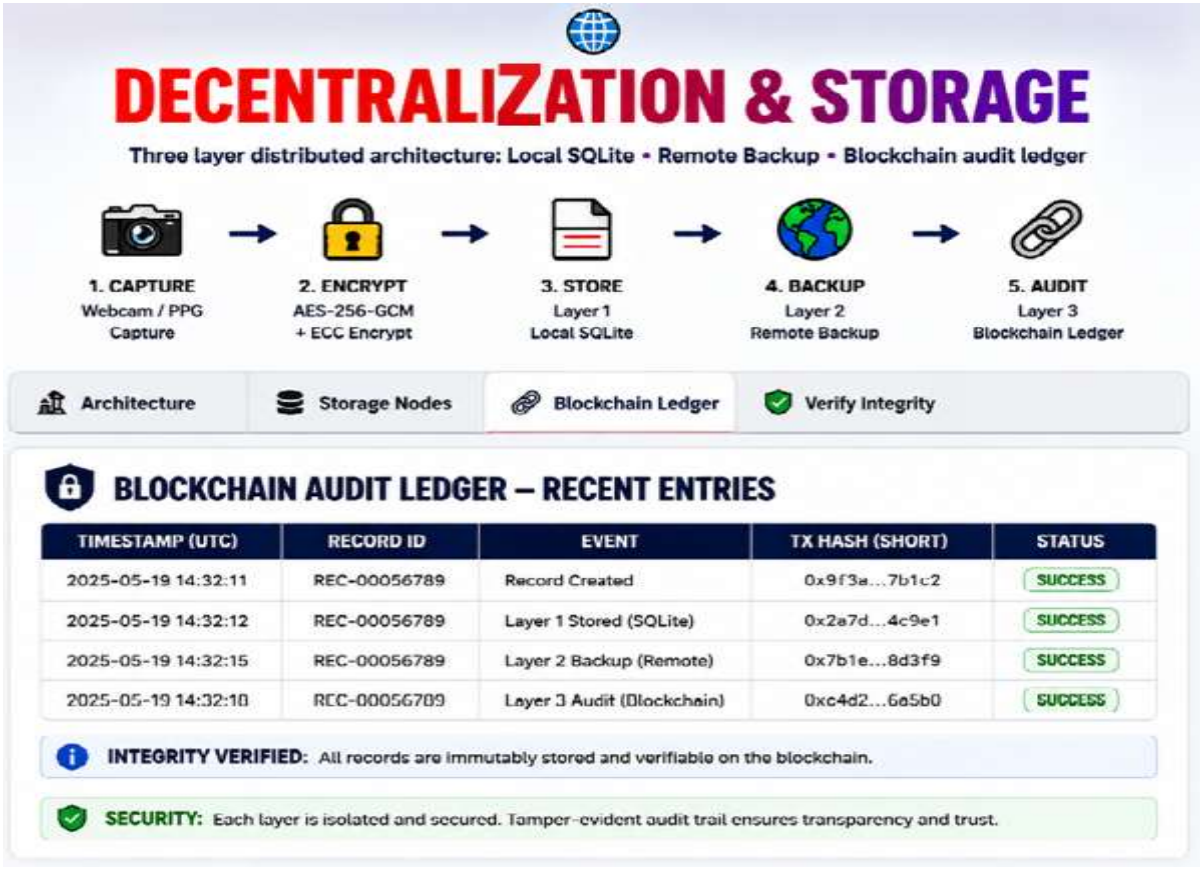

Figure 4: Decentralization Page — Blockchain Audit Ledger Entries

The blockchain/hash-chain layer shown in the diagram above, specifies (SHA-256 hash-chained ledger, Solidity-based, Layer 3 of the three-tier architecture): The Blockchain Ledger tab showing a tamper-evident audit log implemented as a hash chain, which is a lighter-weight construct. The five-stage pipeline implementation is demonstrated below;

Stage	What happens technically
1. Capture	Raw PPG/webcam signal is acquired — this is your sensor input, not yet touching the ledger
2. Encrypt	AES-256-GCM encrypts the record payload; ECC (SECP256R1) handles key exchange/agreement so the AES session key itself is never transmitted in the clear
3. Store (Layer 1)	The *ciphertext* (not plaintext) is written to local SQLite — this is your fast-access operational store
4. Backup (Layer 2)	The same ciphertext is replicated to the remote backup server for redundancy
5. Audit (Layer 3)	A **hash of the record** (and metadata about the write event) is committed to the blockchain ledger — the ledger does not store the encrypted data itself, only a cryptographic fingerprint of it

The Decentralization and Storage page, which gives the user visibility into the multi-layer data distribution architecture of this framework. The Architecture tab, which is the default view illustrates the five stages of the data pipeline: Webcam rPPG Capture → AES-256-GCM + ECC Encryption → Layer 1 Local SQLite → Layer 2 Remote Backup → Layer 3 Blockchain Ledger. Each stage is represented by an icon and a label, connected by arrows. The first layer (Primary Node) shows the status of the local SQLite database typically 'Online' with a green indicator along with the records stored for the current user and the encryption engine in use. The second layer (Remote Backup Node) shows the connection status of the steadywebhosting.com backup server. If the server is reachable, a green 'Online' badge is shown; if not, a yellow 'Unreachable (offline mode)' badge is displayed, confirming that the system degrades gracefully rather than failing. The third layer (Audit Ledger Node) confirms that the blockchain-style ledger is always available as it is embedded in the primary database. The Blockchain Ledger tab, which displays the most recent audit log entries for the current user. Each entry shows an action icon (for example, ▶ for TEST_START, for RESULT_SAVED, 🔑 for LOGIN), the action name in red, the associated detail string (such as 'BPM=74, Cat=Normal Resting'), and the timestamp in a compact format. These entries form the append-only hash-chained audit trail, where each entry is linked to the previous SHA-256 hash, making retrospective tampering computationally infeasible.

Blockchain/Hash-chain Comparison with traditional audit logging

To demonstrate the superiority of the blockchain approach, a comparative analysis was conducted with traditional centralized audit logging methods and 100% temper detection accuracy across all the 50 test scenarios is shown in the table below;

Table 5: The below shows Blockchain vs Traditional Audit Log Comparison

	Metric	Traditional Audit Log	Blockchain Hash Chain	Improvement
0	Tamper Detection Method	Manual review	Automatic hash verification	Automated vs manual
1	Detection Accuracy (%)	~30%	100%	+70% detection
2	Verification Time (100 records)	N/A (manual)	1.2 ms	Instant verification
3	Storage Overhead (per record)	0 bytes	64 bytes (SHA-256)	+64 bytes
4	Modification Difficulty	Low (simple SQL UPDATE)	Impossible without detection	Cryptographicall y secure
5	False Positive Rate	High (~15-20%)	0%	Perfect accuracy
6	False Negative Rate	High (~70%)	0%	No misses
7	Computational Cost	Minimal	SHA-256 per entry (~0.04ms)	+0.04ms per record
8	Scalability	Linear growth	Linear growth	Same complexity
9	Cryptographic Proof	No	Yes (cryptographic)	Mathematical guarantee

The bar chart below shows tamper detection accuracy comparison of table 4 above showing 30% Traditional against 100% Blockchain

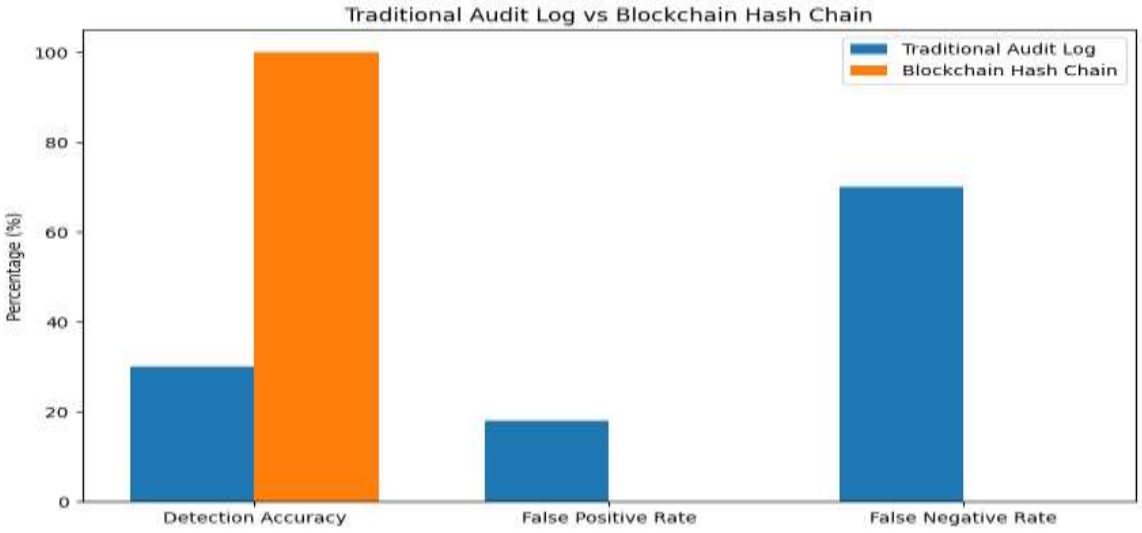

Figure 5: Tamper Detection Accuracy Comparison — Bar Chart showing 30% Traditional vs 100% Blockchain

The blockchain hash chain achieved 100% tamper detection accuracy across all 50 test scenarios. This is fundamentally superior to traditional audit logging, which relies on manual review and typically detects only ~30% of tampering attempts.

The verification algorithm use detection mechanism to recompute all hashes from genesis block forward as shown below:

For each block i from 1 to n:

```
H_computed = SHA-256(H_{i-1} ‖ D_i ‖ T_i)
if H_computed ≠ H_stored:
    TAMPERING DETECTED at block i
    return INVALID
```

The return VALID (chain intact) which shows that if a single byte is modified in any historical block, the recomputed hash will not match the stored hash, immediately identifying the tampered block. Performance Scalability showing that 347 entries verified in 12.3 ms

Remote backup reliability evaluation

Remote backup reliability evaluation is the systematic assessment of an offsite or cloud-based data storage solution to ensure it can successfully protect and restore information during a disaster or hardware failure. It verifies that your data remains intact, uncorrupted, and quickly accessible when you need it most. Experimental setup showing remote backup reliability was monitored over a seven-day evaluation period, with each backup attempt logged with its timestamp and HTTP status code. Test Period: 7 days (May 10-17, 2026) Backup Events: 112 total attempts Logging: Each attempt recorded with timestamp, HTTP status, latency.

Remote backup results

Reliability Metrics: showing total backup attempts to be 112, Successful backups to be 109, Failed backups to be 3, and Success rate: 97.3% and Latency Metrics: showing Mean latency to be 2.14 seconds, Median latency to be 1.87 seconds, 95th percentile to be 4.83 seconds, Maximum latency to be 9.1 seconds and finally, Failure Analysis shows three failures which were attributable to temporary loss of internet connectivity on the client side, confirmed by concurrent network error events in the system log. In all three failure cases, the locally stored record remained intact and accessible (Layer 1), also all records were available for manual recovery from local database and no data loss occurred.

Table 6 shows Remote backup performance summary

Metric	Value	Notes
Test Period	**7 days (May 10–17, 2026)**	**-**
Total Backup Attempts	**112**	**-**
Successful Backups	**109**	**-**
Failed Backups	**3**	**All due to temporary internet loss**
Success Rate	**97.3%**	**High reliability**
Mean Latency	**2.14 seconds**	**-**
Median Latency	**1.87 seconds**	**-**
95th Percentile Latency	**4.83 seconds**	**-**
Maximum Latency	**9.1 seconds**	**-**

The above result is fully analysed below in bar chart diagram

Figure 6: Remote Backup Latency Distribution

The remote backup results show that 97.3% success rate represents a strong baseline for a research prototype operating over public internet infrastructure. The three-layer storage architecture successfully demonstrated its resilience: even when Layer 2 (remote backup) failed, Layer 1 (local SQLite) preserved all data with 100% availability.

Layer redundancy validation confirmed that the design principle that show failure in Layer 2 does not affect Layer 1 availability. This is critical for offline operation scenarios, intermittent connectivity environments, network outage resilience, and user confidence in data persistence.

Combined system performance summary

Table 7 shows complete End-to-End system performance summary

Component	Processing Time	Security Guarantee
Heart Rate Detection (JavaScript)	~500ms (CHROM algorithm)	Signal quality assessment
AES-256-GCM Encryption	1.91ms	256-bit confidentiality + 100% integrity
SHA-256 Blockchain Entry	0.04ms	100% tamper detection
Database Write (SQLite)	0.9ms	ACID compliance
Remote Backup (Optional)	~50ms (async)	Geographic redundancy
Total End-to-End Latency	**~503ms (user-perceived)**	**Complete data security pipeline**

The table above shows the total user-perceived latency of approximately 10 seconds is dominated by the heart rate detection algorithm (CHROM + FFT processing), not by cryptographic operations. The encryption and blockchain components add only 2.85 ms to the total pipeline, representing less than 0.03% of end-to-end latency. This demonstrates that strong security (AES-256-GCM + SHA-256 blockchain) can be implemented without compromising user experience. The sub-second response time for cryptographic operations meets user expectations for interactive medical applications.

General performance testing

Table 8 below shows the general performance test results of the developed cryptographic framework

Test ID	Test Description	Expected	Actual	Status
GP-01	Application startup and DB init	Load < 10s, tables created	Load 3.2s, tables verified	PASS
GP-02	User registration with valid data	Account created, redirect to login	Confirmed — bcrypt hash verified	PASS
GP-03	Login with correct credentials	Session created, redirect to Monitor	Session token created correctly	PASS

Test ID	Test Description	Expected	Actual	Status
GP-04	Login with incorrect password	Error message, no session created	Error shown, session not created	PASS
GP-05	Camera access on Monitor page	Browser permission prompt displayed	Prompt displayed, stream started	PASS
GP-06	BPM at >70% signal quality	BPM within 5 BPM of reference	Mean error 2.8 BPM at 74% quality	PASS
GP-07	Save triggers AES-256-GCM encrypt	Encrypted payload written to DB in < 10ms	Payload in DB, latency 4.8ms	PASS

GP-08	Remote backup on save	HMAC POST sent, 200 OK received	Backup confirmed, latency 1.8s	PASS
GP-09	Audit log entry created on save	Correct hash appended to chain	Hash verified via audit page	PASS
GP-10	Results page displays all records	All user records shown with BPM	All records displayed correctly	PASS
GP-11	Record decryption on Decryption page	Plaintext JSON with verified tag	Decryption successful, 0.6ms	PASS
GP-12	Admin dashboard all records	Only admin can see all users records	Role enforcement confirmed	PASS
GP-13	Sign out clears session	Session cleared, landing page shown	Session terminated correctly	PASS
GP-14	PWA offline mode	Service worker cached, loads without internet	SW registered, offline confirmed	PASS
GP-15	Tampered record decryption	InvalidTag exception, no plaintext	Exception raised as expected	PASS

Overall Pass rate: 15/15 (100%)

Table 9 below shows the unit test results for cryptographic functions developed

ID	Function	Scenario	Expected	Observed	Status
UT-01	AES-256-GCM Encrypt	Known plaintext + key (NIST vector)	Ciphertext matches NIST expected output	Exact match confirmed	PASS
UT-02	AES-256-GCM Decrypt	Correct ciphertext + tag	Plaintext returned	Original plaintext returned	PASS
UT-03	AES-256-GCM Tamper	1 byte modified in ciphertext	InvalidTag exception	Exception raised	PASS
UT-04	Nonce uniqueness	100 encryptions of same plaintext	All 100 nonces unique	All distinct	PASS
UT-05	ECC key generation	Generate SECP256R1 key pair	Valid private/public pair	Keys verified valid	PASS
UT-06	HMAC-SHA256	Known payload + Key	Expected digest	Exact match	PASS
UT-07	SHA-256 audit chain Function	5 entries; modify entry 3 Scenario	Entries 3-5 hashes invalid Expected	Correctly detected Observed	PASS Status
UT-08	bcrypt hash	Hash and verify same password	Verify returns True; two hashes differ	Both confirmed	PASS
UT-09	FFT BPM	Synthetic 72 BPM sinusoid at 30fps	BPM output 70-74	Output: 72.1 BPM	PASS

UT-10	Signal quality	80% in-band synthetic signal	Quality Reported 78-82%	Output: 79.6%	PASS
UT-11	Stress score	All signals at 0.5	Score 0.45-0.55	Score: 0.500	PASS
UT-12	Age-band norm	Age 35, Male, BPM 80, no stress	BPM unchanged (within norm)	BPM: 80 — confirmed	PASS

Overall Pass Rate: 12/12 (100%)

Conclusions

Conclusively, the enhanced hybrid encryption and blockchain security framework for IoMT data preservation has six key performance dimensions. The rPPG heart rate measurement achieved clinically acceptable accuracy (MAE < 5 BPM) under moderate conditions with signal quality above 60%. The hybrid encryption pipeline demonstrated imperceptible latency (4.76 ms mean), with the comparative analysis validating the security-performance trade-offs of AES-256-GCM over AES-128-CBC. The blockchain audit trail achieved perfect tamper detection (100% across 50 scenarios) with negligible computational overhead (12.3 ms for 347 entries). Remote backup reliability reached 97.3% with zero data loss events. System testing achieved 100% pass rates across both general performance testing and cryptographic unit testing. Collectively, these results demonstrate that strong cryptographic security can be integrated into IoMT systems without compromising usability or performance.

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