RESPONSE LETTER

Manuscript Title: "Blockchain and Biometrics: Survey, GDPR Elements, and Future Directions"

Manuscript ID: TBIOM-2024-04-0042

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We would like to sincerely thank the editor-in-chief, associate editor, and respected reviewers for their insightful comments and suggestions. We have revised the manuscript accordingly, and all feedback has been carefully addressed. Our responses are provided directly below each comment.

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EDITOR-IN-CHIEF :

Comments to the Author:

Clearly there is work of interest here, but there appear to be some major improvements to be made. Please follow the excellent comments from the reviewers and AE when preparing the revised version which is to be submitted as new paper. Pls note that the diversity of reviews here reflects a difference in standards and we confirm the AE view that by these comments the paper should be revised and resubmitted as a new paper, for which some excellent guidance is included in the reviews.

ASSOCIATE EDITOR:

Comments to the Author:

The manuscript reviews existing attempts in the literature that utilize blockchain for biometrics and discusses some of the legal challenges. The three reviewers have provided a mixed opinion about the manuscript. After carefully analyzing the reviews and the manuscript, it is clear that the paper requires substantial modification before being accepted for publication. Hence, the authors are encouraged to incorporate the following changes and resubmit the manuscript as new. The AE also apologizes for the long delay in processing this manuscript.

1) First and foremost, a review paper needs to be self-contained. Since this manuscript deals with blockchain and biometrics, a brief introduction to these technologies and their intersection points must be presented. For example, what is the process involved in a typical blockchain transaction? How does this process intersect with a typical biometrics workflow? A system diagram must be included to illustrate these aspects.

Response: Thank you for bringing this important point to our attention. We have added a brief introduction section (Section II) that includes the information requested.

2) The manuscript lacks a clear description of the end-to-end protocols for biometric enrollment and authentication based on blockchain.

Response: This is now provided in Section II, Subsection C.

Section 2 directly jumps into the challenges involved in using blockchain for biometrics. It appears to focus on a singular aspect of using blockchain for biometric data storage and discusses issues such

as on-chain vs. off-chain storage (Table I). Why does one need smart contracts and consensus for a biometric recognition task? If the goal is to ensure properties such as auditability and accountability, can't this be achieved by storing the authentication log on a blockchain (instead of the biometric data itself)?

Response: Please refer to Section III, Subsection B for our detailed response.

3) The manuscript claims that a blockchain can be used to implement a PKI platform without bothering to explain how this can be achieved and how this will be different from existing PKI platforms. Even assuming a "better" PKI platform can be implemented using blockchain, the manuscript must explain how this platform helps a biometric system.

Response: Your concern has been addressed expanding Section V, Subsection B, Item 3.

4) Section 2-E already concludes that on-chain storage of biometric templates is hazardous for data privacy, and blockchain is unsuitable for real-time authentication applications. After this conclusion, sections 3 and 4 again proceed to argue the same thing again and again. The whole organization of the paper needs to be revisited to avoid such repetitions.

Response: We apologize for the inconvenience. We have revisited the overall structure of our paper to avoid such repetition.

5) The entire legal analysis section is based only on GDPR and lacks reference to any other national laws and international regulations/standards. Either the legal analysis must be expanded to include other laws or it should be explicitly stated that the analysis is based only on GDPR.

Response: We have addressed this concern by explicitly stating that the analysis is based only on GDPR throughout the paper and also modifying the paper title to become: “Blockchain and Biometrics: Survey, GDPR Elements, and Future Directions”

6) As explained earlier, the proposed recommendations in Section IV-A are fairly obvious from the discussion in Section II. The use cases discussed in Section IV-B are generic and lack specific application scenarios. As one of the reviewers indicated, the content is superficial in most places.

Response: We have provided additional details for all discussed use cases to address the concern raised by the respected associate editor.

7) Finally, the manuscript comes out more as a position paper that presents the authors' views rather than a comprehensive survey paper that analyzes the existing literature on the topic and organizes this prior work based on some taxonomy.

Response: This survey is based on insights gathered from papers across various fields related to blockchain and biometrics. The authors have intentionally refrained from promoting any particular viewpoint. Instead, the goal has been to connect existing interdisciplinary works, combining knowledge from both blockchain and biometrics to provide deeper insight into their integration.

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REVIEWERS
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REVIEWER 1
Recommendation: Author Should Prepare A Minor Revision

Comments:
See the attached report (attached here at the end of the document)

Additional Questions:
1. Which category describes this manuscript?: Survey/Tutorial/How-To

2. How relevant is this manuscript to the readers of this periodical? If you answer Not very relevant or Irrelevant please explain your rating under Public Comments below.: Very Relevant

1. Please evaluate the significance of the manuscript's research contribution.: Excellent

2. Please explain how this manuscript advances this field of research and/or contributes something new to the literature.: **See the attached report**
Response: We have carefully addressed all the suggestions provided in the attached report.

3. Is the manuscript technically sound? In the Public Comments section, please provide detailed explanations to support your assessment: Yes

4. How thorough is the experimental validation (where appropriate)? Please discuss any shortcomings in the Public Comments section.: Not applicable to this paper

1. Are the title, abstract, and keywords appropriate? If not, please comment in the Public Comments section.: Yes

2. Does the manuscript contain sufficient and appropriate references? Please comment and include additional suggested references in the Public Comments section.: Important references are missing; more references are needed

If you are suggesting additional references they must be entered in the text box provided. All suggestions must include full bibliographic information plus a DOI.
: See the attached report

3. Does the introduction state the objectives of the manuscript in terms that encourage the reader to read on? If not, please explain your answer in the Public Comments section.: Could be improved

4. How would you rate the organization of the manuscript? Is it focused? Please elaborate with

suggestions for reorganization in the Public Comments section.: Satisfactory

5. Please rate the readability of the manuscript. Explain your rating under Public Comments below.: Easy to read

6. How is the length of the manuscript? If changes are suggested, please make explicit recommendations in the Public Comments section.: About right

7. Should the supplemental material be included? (Click on the Supplementary Files icon to view files): Does not apply, no supplementary files included

8. If yes to 7, should it be accepted:

Please rate the manuscript overall. Explain your choice.: Excellent

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REVIEWER 2
Recommendation: Revise and resubmit as "new"

Comments:
1. While the paper presents a limitation and strength of the technology majority of this is presented concerning blockchain but not related to biometric + blockchain.

Response: We have made significant efforts to address this issue by refining the content, ensuring that the respected reviewer does not have this impression anymore.

2. The practical aspect of this combination of strength and weakness is missing. While the authors have provided Table 2 it is neither sufficient nor discussed adequately.

Response: Section III covers the practical aspects of integrating blockchain and biometrics, addressing nearly all key considerations for this combination.

3. In most of the places, generic terminology has been used. (i) Line 42 page 2 right side, describes the storage issue but concerning biometrics it is not clean, how much data needs to be stored. Since the biometric systems generally require a single gallery for verification, is the computational cost high? For how big an organization, this issue can be avoided, any comments?

Response: The answers to these questions are provided in Section III, Subsection A, particularly in Item 1 (Storage) and Item 3 (Computation Cost).

(ii) What is the meaning of transaction in terms of biometrics data processing (authentication etc) (line 12 page 3)?

Response: Please refer to Section II, Subsection C.

What and how many transactions need to be stored?

Response: Please refer to Section II, Subsection C, and Section III, Subsection A, Item 3.

(iii) In the case of biometrics what is the meaning of adding a new block? Is it related to the addition of a new identity?

Response: Please refer to Section II, Subsection C.

(iv) Line 29 page 3 and line 15 on page 5: "It still limits some biometric applications": specific examples would be helpful.

Response: It is provided in Section II, Subsection A, Item 2.

5. The content in many places is superficial. For example: "Since biometric applications are resource intensive": What are the applications? And for what kind of application, the use of biometric + blockchain is feasible? In other words, is the combination more effective for gender recognition than identity authentication or vice versa?

Response: We have gone through the full paper removing superficial elements and, where appropriate, introducing concrete concepts, terms, and examples, e.g., see Section V, Subsection B, Item 3 where a practical biometrics+blockchain application using iris biometrics is discussed (Worldcoin).

Additional Questions:
1. Which category describes this manuscript?: Survey/Tutorial/How-To

2. How relevant is this manuscript to the readers of this periodical? If you answer Not very relevant or Irrelevant please explain your rating under Public Comments below.: Not very relevant

1. Please evaluate the significance of the manuscript's research contribution.: Fair - Even with the recommended changes, the contribution of this paper is unlikely be significant enough for publication.

2. Please explain how this manuscript advances this field of research and/or contributes something new to the literature.: The paper discusses how the combination of blockchain and biometrics can advance the field of privacy, identity authentication, and data storage.

3. Is the manuscript technically sound? In the Public Comments section, please provide detailed explanations to support your assessment: No

4. How thorough is the experimental validation (where appropriate)? Please discuss any shortcomings in the Public Comments section.: Not applicable to this paper

1. Are the title, abstract, and keywords appropriate? If not, please comment in the Public Comments section.: Yes

2. Does the manuscript contain sufficient and appropriate references? Please comment and include

additional suggested references in the Public Comments section.: References are sufficient and appropriate

If you are suggesting additional references they must be entered in the text box provided. All suggestions must include full bibliographic information plus a DOI.
: N/A

3. Does the introduction state the objectives of the manuscript in terms that encourage the reader to read on? If not, please explain your answer in the Public Comments section.: Yes

4. How would you rate the organization of the manuscript? Is it focused? Please elaborate with suggestions for reorganization in the Public Comments section.: Satisfactory

5. Please rate the readability of the manuscript. Explain your rating under Public Comments below.: Readable - but requires some effort to understand

6. How is the length of the manuscript? If changes are suggested, please make explicit recommendations in the Public Comments section.: Should be trimmed a bit

7. Should the supplemental material be included? (Click on the Supplementary Files icon to view files): Does not apply, no supplementary files included

8. If yes to 7, should it be accepted:

Please rate the manuscript overall. Explain your choice.: Fair

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REVIEWER 3
Recommendation: Accept With No Changes

Comments:
This abstract provides a survey of recent research on integrating blockchain technology with biometric recognition systems. The paper highlights the unique benefits of biometrics—such as being hard to forge and efficient for identity verification—and discusses the growing popularity of blockchain for decentralized applications in various industries, such as finance, IoT, healthcare, and logistics.
The authors note that while the combination of these two technologies holds promise, it remains in its early stages. They review 36 technical papers to explore the potential advantages and drawbacks from both technical and legal perspectives. Some benefits include the use of blockchain for Public Key Infrastructure (PKI), distributed identity management, federated learning, and multimodal biometrics. However, challenges such as blockchain's current inefficiency and lack of real-time performance, along with concerns over storing sensitive biometric data on-chain, limit its current practical applications.
From a legal perspective, the paper addresses accountability issues and the complexities of conducting thorough Data Protection Impact Assessments (DPIA). It emphasizes the importance of keeping raw biometric data and templates off-chain to mitigate privacy risks. The legal analysis also

notes the need to clarify the purpose of data processing and assess risks to apply adequate safeguards, particularly considering GDPR requirements, such as the right to be forgotten (Article 17). In conclusion, the paper provides recommendations for aligning legal and technical research in this domain and encourages further research to improve blockchain's efficiency and address legal concerns in future biometric blockchain applications.

Suggestions: Some block diagram can be included various theoretical concepts can be overviewed from a bird-eye point.

Response: Thank for your suggestion, you are totally right. We have added 4 new Figures based on your suggestion (Figs. 1 to 4).

Additional Questions:
1. Which category describes this manuscript?: Survey/Tutorial/How-To

2. How relevant is this manuscript to the readers of this periodical? If you answer Not very relevant or Irrelevant please explain your rating under Public Comments below.: Relevant

1. Please evaluate the significance of the manuscript's research contribution.: Good

2. Please explain how this manuscript advances this field of research and/or contributes something new to the literature.: 1. suggested new applications, like using blockchain to enhance PKI and proposed multimodal biometrics on decentralized networks.
2. addressed GDPR compilance issues and an interdisciplinary perspective on reconciling blockchain's immutability with privacy laws.

3. Is the manuscript technically sound? In the Public Comments section, please provide detailed explanations to support your assessment: Yes

4. How thorough is the experimental validation (where appropriate)? Please discuss any shortcomings in the Public Comments section.: Not applicable to this paper

1. Are the title, abstract, and keywords appropriate? If not, please comment in the Public Comments section.: Yes

2. Does the manuscript contain sufficient and appropriate references? Please comment and include additional suggested references in the Public Comments section.: References are sufficient and appropriate

If you are suggesting additional references they must be entered in the text box provided. All suggestions must include full bibliographic information plus a DOI.
: NA

3. Does the introduction state the objectives of the manuscript in terms that encourage the reader to

read on? If not, please explain your answer in the Public Comments section.: Yes

4. How would you rate the organization of the manuscript? Is it focused? Please elaborate with suggestions for reorganization in the Public Comments section.: Satisfactory

5. Please rate the readability of the manuscript. Explain your rating under Public Comments below.: Easy to read

6. How is the length of the manuscript? If changes are suggested, please make explicit recommendations in the Public Comments section.: About right

7. Should the supplemental material be included? (Click on the Supplementary Files icon to view files): Does not apply, no supplementary files included

8. If yes to 7, should it be accepted:

Please rate the manuscript overall. Explain your choice.: Good