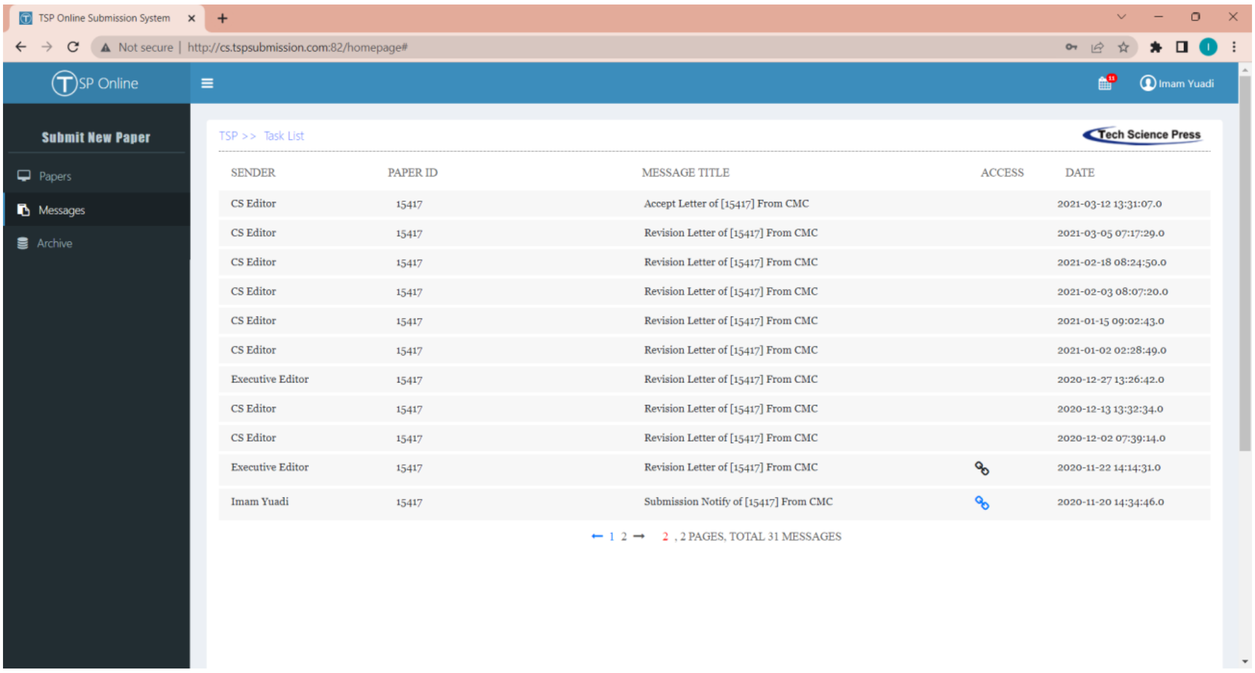
Correspondence for Journal Submission

Digital Forensics for Skulls Classification in Physical Anthropology Collection Management

I Yuadi, MD Artaria, S Asyhari, AT Asyhari

Computers, Materials and Continua 68 (3), 3979-3995

1. All Correspondence



SENDER	PAPER ID	MESSAGE TITLE	ACCESS	DATE
CS Editor	15417	Accept Letter of [15417] From CMC		2021-03-12 13:31:07.0
CS Editor	15417	Revision Letter of [15417] From CMC		2021-03-05 07:17:29.0
CS Editor	15417	Revision Letter of [15417] From CMC		2021-02-18 08:24:50.0
CS Editor	15417	Revision Letter of [15417] From CMC		2021-02-03 08:07:20.0
CS Editor	15417	Revision Letter of [15417] From CMC		2021-01-15 09:02:43.0
CS Editor	15417	Revision Letter of [15417] From CMC		2021-01-02 02:28:49.0
Executive Editor	15417	Revision Letter of [15417] From CMC		2020-12-27 13:26:42.0
CS Editor	15417	Revision Letter of [15417] From CMC		2020-12-13 13:32:34.0
CS Editor	15417	Revision Letter of [15417] From CMC		2020-12-02 07:39:14.0
Executive Editor	15417	Revision Letter of [15417] From CMC		2020-11-22 14:14:31.0
Imam Yuadi	15417	Submission Notify of [15417] From CMC		2020-11-20 14:34:46.0

Cover Letter

Department of Information and Library Science,

Airlangga University, Indonesia

Dear CMC Editors

We are interested in submitting a paper to Computers, Materials & Continua journal. Our paper entitled: "Digital Forensics for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management ". We can confirm that this paper was not published, and we are not considering it for publication elsewhere. We can also confirm our work is original.

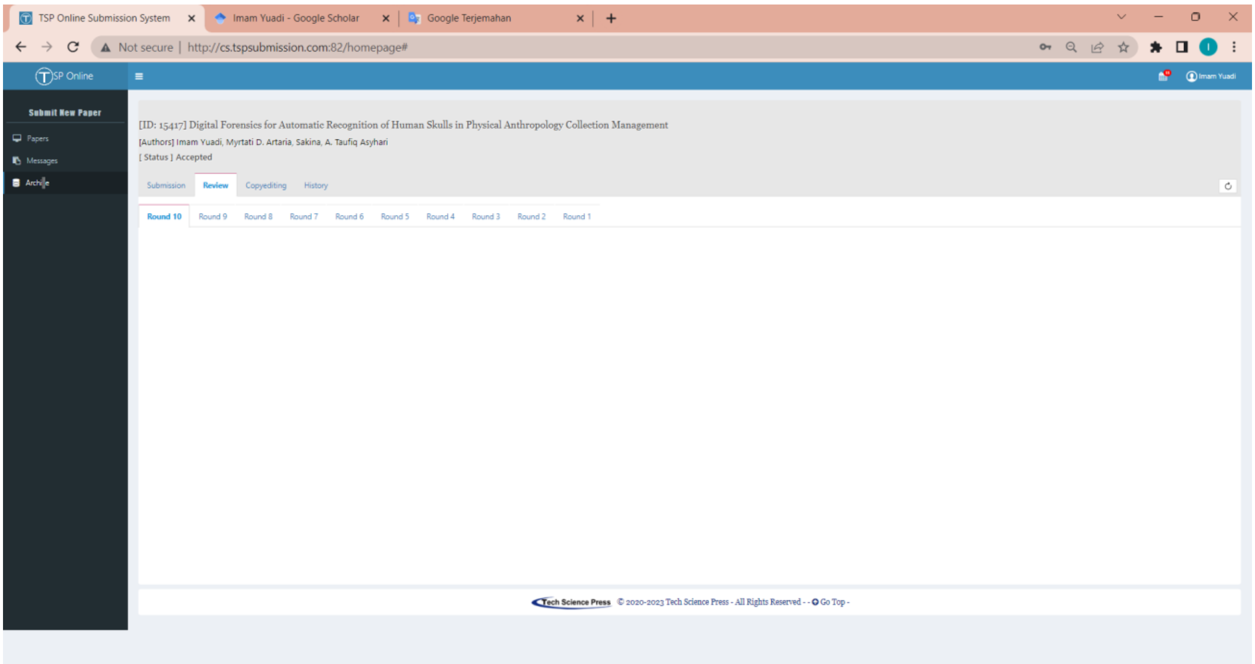
I can confirm all the authors have read the final version of the paper and approved submission to the journal. All authors accept full responsibility for the paper including its delivery and contents. I can confirm and in agreement with the other authors that there are no ethical, copyright or disclosure issues that come with this paper. I can also confirm that there are no conflicts of interest to be declared in relation to this submission.

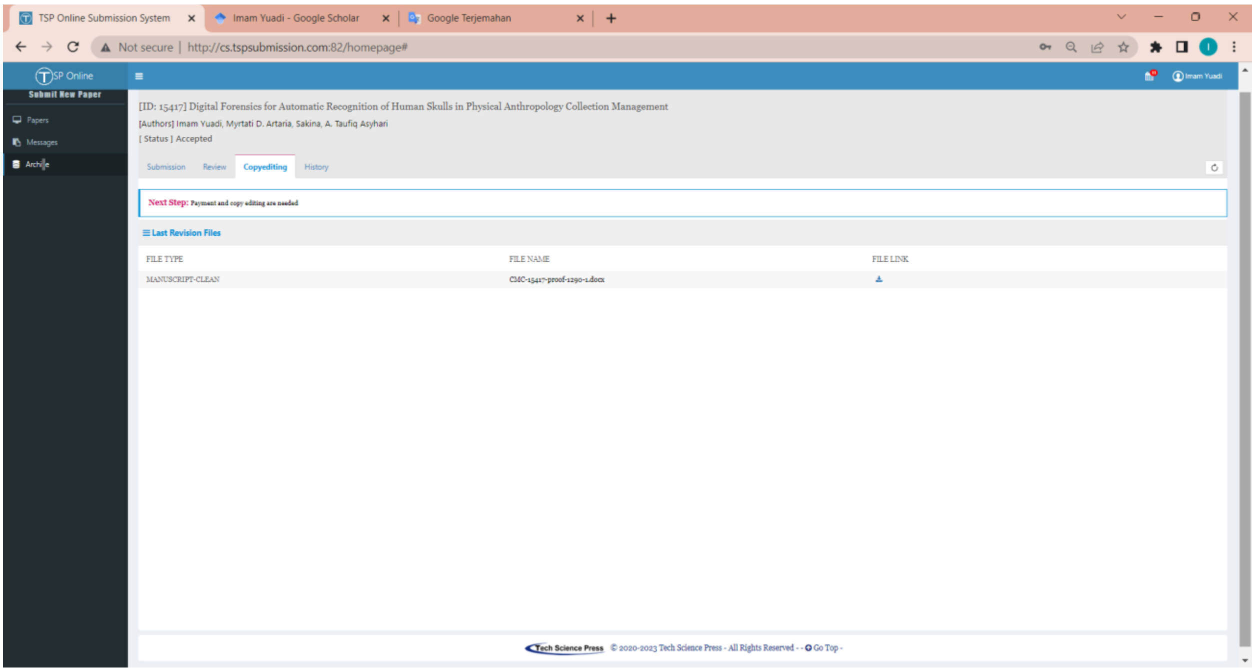
Finally, I can confirm we are committed to paying the articles processing charge (APC) if the paper is accepted.

Kind regards

Imam Yuadi

(on behalf of all the authors)





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[ID: 15417] Digital Forensics for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management

[Authors] Imam Yuadi, Myrtati D. Artaria, Sakina, A. Taufiq Asyhari

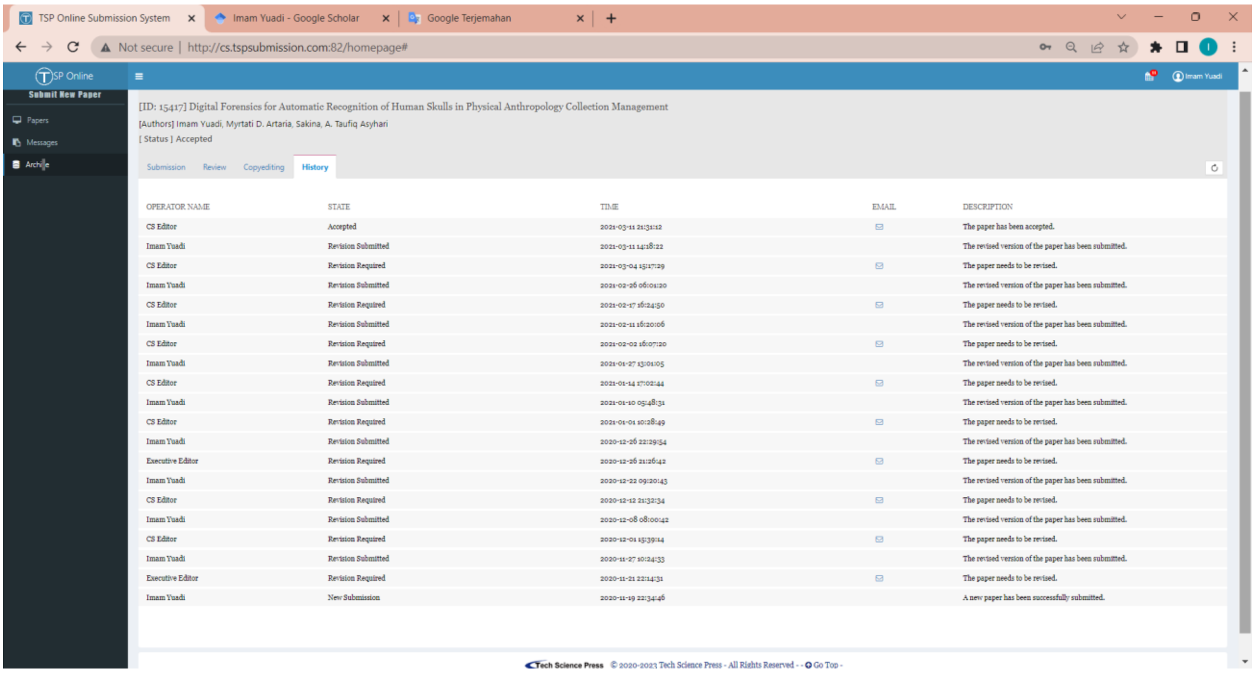
[Status] Accepted

Submission | Review | **Copyediting** | History

Next Step: Payment and copy editing are needed

Last Revision Files

FILE TYPE	FILE NAME	FILE LINK
MANUSCRIPT-CLEAN	CMC-15417-proof-1290-1.docx	⬇



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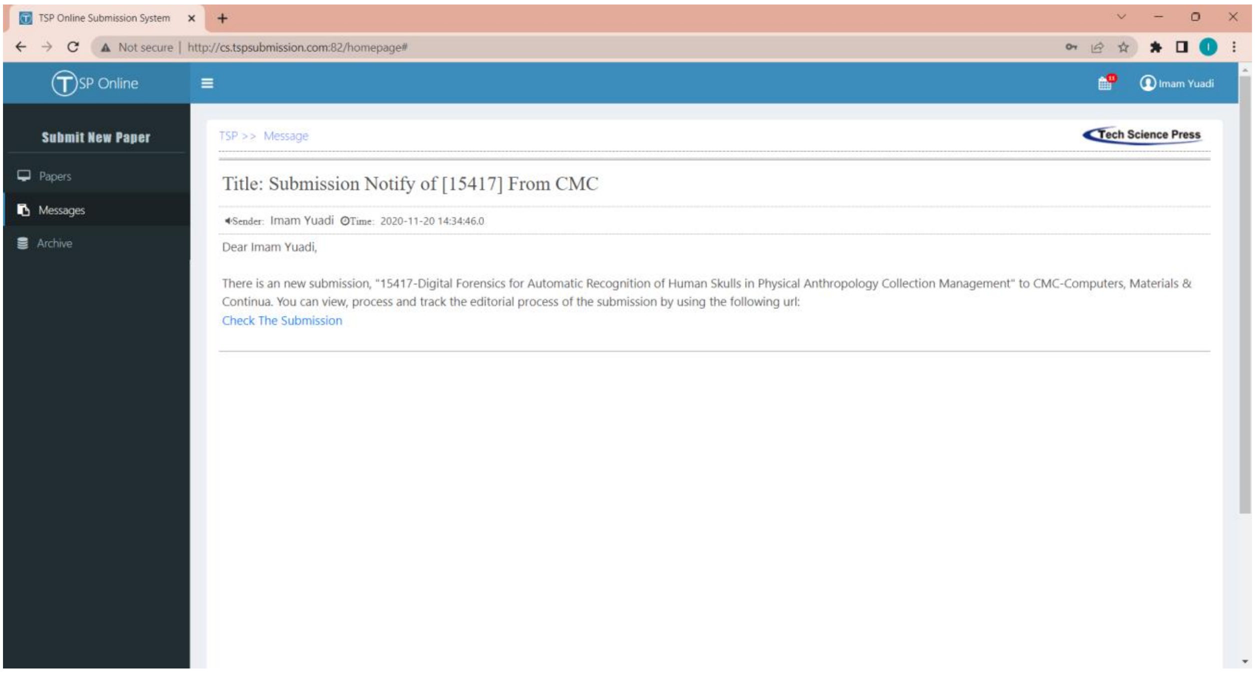
[Status] Accepted

Submission | Review | Copyediting | **History**

OPERATOR NAME	STATE	TIME	EMAIL	DESCRIPTION
CS Editor	Accepted	2021-03-11 21:31:12	✉	The paper has been accepted.
Imam Yuadi	Revision Submitted	2021-03-11 14:18:22		The revised version of the paper has been submitted.
CS Editor	Revision Required	2021-03-04 15:17:29	✉	The paper needs to be revised.
Imam Yuadi	Revision Submitted	2021-02-26 06:01:20		The revised version of the paper has been submitted.
CS Editor	Revision Required	2021-02-17 16:24:50	✉	The paper needs to be revised.
Imam Yuadi	Revision Submitted	2021-02-11 16:20:06		The revised version of the paper has been submitted.
CS Editor	Revision Required	2021-02-02 16:07:20	✉	The paper needs to be revised.
Imam Yuadi	Revision Submitted	2021-01-27 13:01:05		The revised version of the paper has been submitted.
CS Editor	Revision Required	2021-01-14 17:02:44	✉	The paper needs to be revised.
Imam Yuadi	Revision Submitted	2021-01-10 05:48:31		The revised version of the paper has been submitted.
CS Editor	Revision Required	2021-01-01 10:28:49	✉	The paper needs to be revised.
Imam Yuadi	Revision Submitted	2020-12-26 22:29:54		The revised version of the paper has been submitted.
Executive Editor	Revision Required	2020-12-26 21:26:42	✉	The paper needs to be revised.
Imam Yuadi	Revision Submitted	2020-12-22 09:20:43		The revised version of the paper has been submitted.
CS Editor	Revision Required	2020-12-12 21:32:34	✉	The paper needs to be revised.
Imam Yuadi	Revision Submitted	2020-12-08 08:00:42		The revised version of the paper has been submitted.
CS Editor	Revision Required	2020-12-01 15:39:14	✉	The paper needs to be revised.
Imam Yuadi	Revision Submitted	2020-11-27 10:24:33		The revised version of the paper has been submitted.
Executive Editor	Revision Required	2020-11-21 22:14:31	✉	The paper needs to be revised.
Imam Yuadi	New Submission	2020-11-19 22:34:46		A new paper has been successfully submitted.

2. Submission Notify of [15417] From CMC



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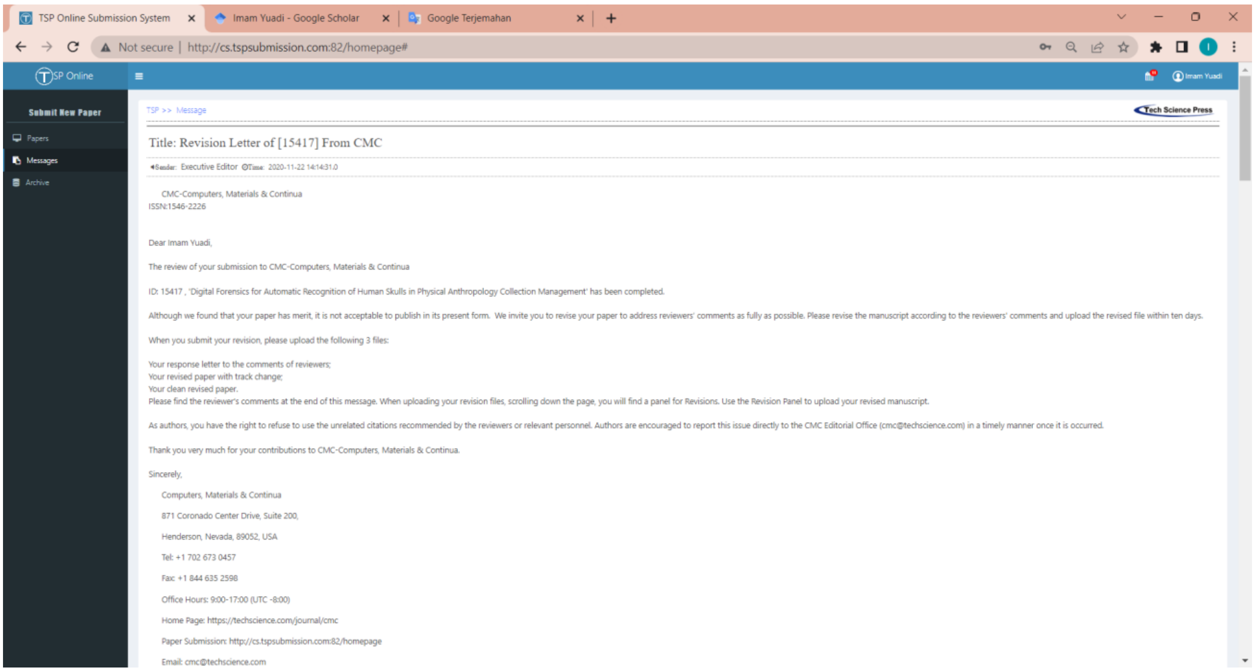
Title: Submission Notify of [15417] From CMC

Sender: Imam Yuadi Time: 2020-11-20 14:34:46.0

Dear Imam Yuadi,

There is an new submission, "15417-Digital Forensics for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management" to CMC-Computers, Materials & Continua. You can view, process and track the editorial process of the submission by using the following url:
Check The Submission

3. Executive Editor: Revision Letter of [15417] From CMC (First Round)



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Title: Revision Letter of [15417] From CMC

Sender: Executive Editor Time: 2020-11-22 14:14:31.0

CMC-Computers, Materials & Continua
ISSN:1546-2226

Dear Imam Yuadi,

The review of your submission to CMC-Computers, Materials & Continua

ID: 15417 , 'Digital Forensics for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management' has been completed.

Although we found that your paper has merit, it is not acceptable to publish in its present form. We invite you to revise your paper to address reviewers' comments as fully as possible. Please revise the manuscript according to the reviewers' comments and upload the revised file within ten days.

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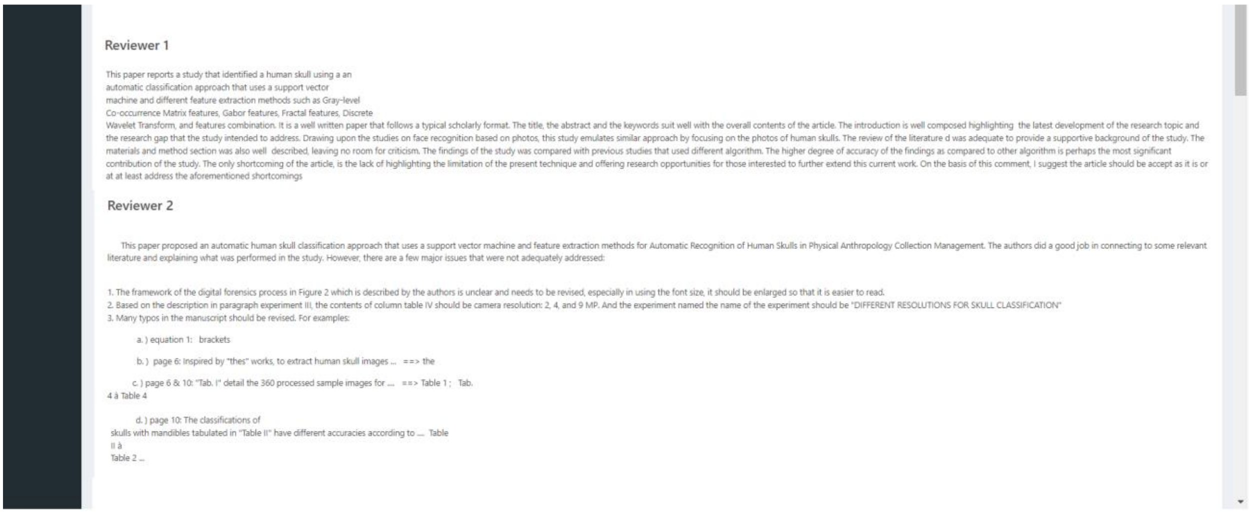

Reviewer 1

This paper reports a study that identified a human skull using a an
automatic classification approach that uses a support vector
machine and different feature extraction methods such as Gray-level
Co-occurrence Matrix features, Gabor features, Fractal features, Discrete
Wavelet Transform, and features combination. It is a well written paper that follows a typical scholarly format. The title, the abstract and the keywords suit well with the overall contents of the article. The introduction is well composed highlighting the latest development of the research topic and the research gap that the study intended to address. Drawing upon the studies on face recognition based on photos, this study emulates similar approach by focusing on the photos of human skulls. The review of the literature d was adequate to provide a supportive background of the study. The materials and method section was also well described, leaving no room for criticism. The findings of the study was compared with previous studies that used different algorithm. The higher degree of accuracy of the findings as compared to other algorithm is perhaps the most significant contribution of the study. The only shortcoming of the article, is the lack of highlighting the limitation of the present technique and offering research opportunities for those interested to further extend this current work. On the basis of this comment, I suggest the article should be accept as it is or at at least address the aforementioned shortcomings

Reviewer 2

This paper proposed an automatic human skull classification approach that uses a support vector machine and feature extraction methods for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management. The authors did a good job in connecting to some relevant literature and explaining what was performed in the study. However, there are a few major issues that were not adequately addressed:

1. The framework of the digital forensics process in Figure 2 which is described by the authors is unclear and needs to be revised, especially in using the font size, it should be enlarged so that it is easier to read.
2. Based on the description in paragraph experiment III, the contents of column table IV should be camera resolution: 2, 4, and 9 MP. And the experiment named the name of the experiment should be "DIFFERENT RESOLUTIONS FOR SKULL CLASSIFICATION"
3. Many typos in the manuscript should be revised. For examples:

a.) equation 1: brackets

b.) page 6: Inspired by "thes" works, to extract human skull images ... ==> the

c.) page 6 & 10: "Tab. I" detail the 360 processed sample images for .... ==> Table 1 ; Tab.
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d.) page 10: The classifications of
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II à
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Selengkapnya

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d.) page 10: The classifications of
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Table 2 ...

Reviewer 3

Please revise your paper in the following parts.

1. Your paper has 16 pages, please shorten it within 15 pages. If you are willing to pay the processing fee for the extra pages beyond 15 pages, you may not shorten your paper within 15 pages.

The authors are requested to be committing to pay an article processing charge (APC) of $1,000 US dollars per processed paper currently. For articles in excess of 15 pages, a mandatory page charge of $100 US dollars per extra page will be required beyond 15 pages.

2. The Corresponding Author of all the authors should be marked with superscript* after superscript[number] and a comma”,” should be used to separate superscript[number] and superscript*.

3. Only the initial letter of the first keyword should be capitalized except Proper Nouns. Please use a semi-colon “ ; ” to separate each keyword.

4. Your Citing References are in the wrong order.

Note: Citing References in the main text should be arranged in order from number [1].

E.g. In your paper, you cite Reference [27, 28] after Reference [2], you should cite Reference [3] after Reference [2], , then you can cite Reference [3-28].

E.g. In your paper, you cite Reference [30-32] after Reference [27-28], you should cite Reference [29] after Reference [27-28], , then you can cite Reference [30--32].

5. Regarding Headings including Level one, two and three headings, the initial letter of each notional word of the Headings should be capitalized. All the headings should be flushed to the left margin.

E.g. In Section 1.2, this should be This.

6. Please add Conflicts of Interest before your references.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

7. Most of your references are not in the right format, please use the CMC new format.

a. Regarding a paper title in a journal or a conference, only the initial letter of the first word except the Proper Nouns should be capitalized. E.g. Reference 1, 2, 12-16, 20-25, …, 50.

b. There should be a word “and” between the last 2 authors or editors. There is no comma “,”before the word “and”. E.g. Reference 39-42.

c. Regarding authors, only the first five authors are listed as they appear. When more than five authors are listed, keep the first five authors and followed by et al. There is no comma **“,”**before the word “et al.”. There is no word **“and”**before the last author. E.g. Reference 16, 26, 28, 50.

d. And you need to provide the authors’ name, the paper title’s name, volume number, issue number, page number and published year as the format: vol. xx, no. xx, pp. xx-xx, published year. The published year should be put at the end of the reference. E.g. Reference 16.

Examples format for journals:

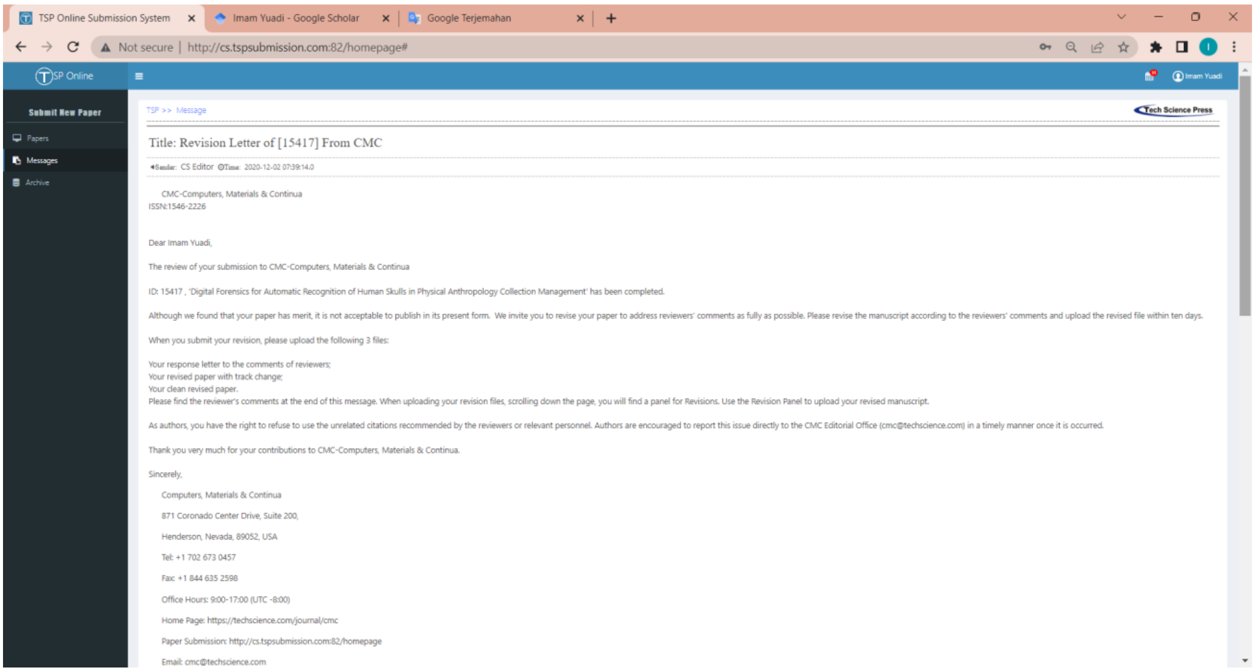
[1] X. F. Li, Y. B. Zhuang and S. X. Yang, “Cloud computing for big data processing,” *Intelligent Automation & Soft Computing*, vol. 23, no. 4, pp. 545–546, 2017.

[2] L. Ali, R. Sidek, I. Aris and M. A. M. Ali, “Design of a testchip for low cost IC testing,” *Intelligent Automation & Soft Computing*, vol. 15, no. 1, pp. 63–72, 2009.

[3] J. Cheng, R. M. Xu, X. Y. Tang, V. S. Sheng and C. T. Cai, “An abnormal network flow feature sequence prediction approach for DDoS attacks detection in big data environment,” *Computers, Materials & Continua*, vol. 55, no. 1, pp. 95–119, 2018.

[4] W. J. Yang, P. P. Dong, W. S. Tang, X. P. Lou, H. J. Zhou *et al.*, “A MPTCP scheduler for web transfer,” *Computers, Materials & Continua*, vol. 57, no. 2, pp. 205–222, 2018.

4. CS Editor: Revision Letter of [15417] From CMC (2nd Round)


Title: Revision Letter of [15417] From CMC

Sender: CS Editor Time: 2020-12-02 07:39:14.0

CMC-Computers, Materials & Continua
ISSN:1546-2226

Dear Imam Yuadi,

The review of your submission to CMC-Computers, Materials & Continua

ID: 15417 , 'Digital Forensics for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management' has been completed.

Although we found that your paper has merit, it is not acceptable to publish in its present form. We invite you to revise your paper to address reviewers' comments as fully as possible. Please revise the manuscript according to the reviewers' comments and upload the revised file within ten days.

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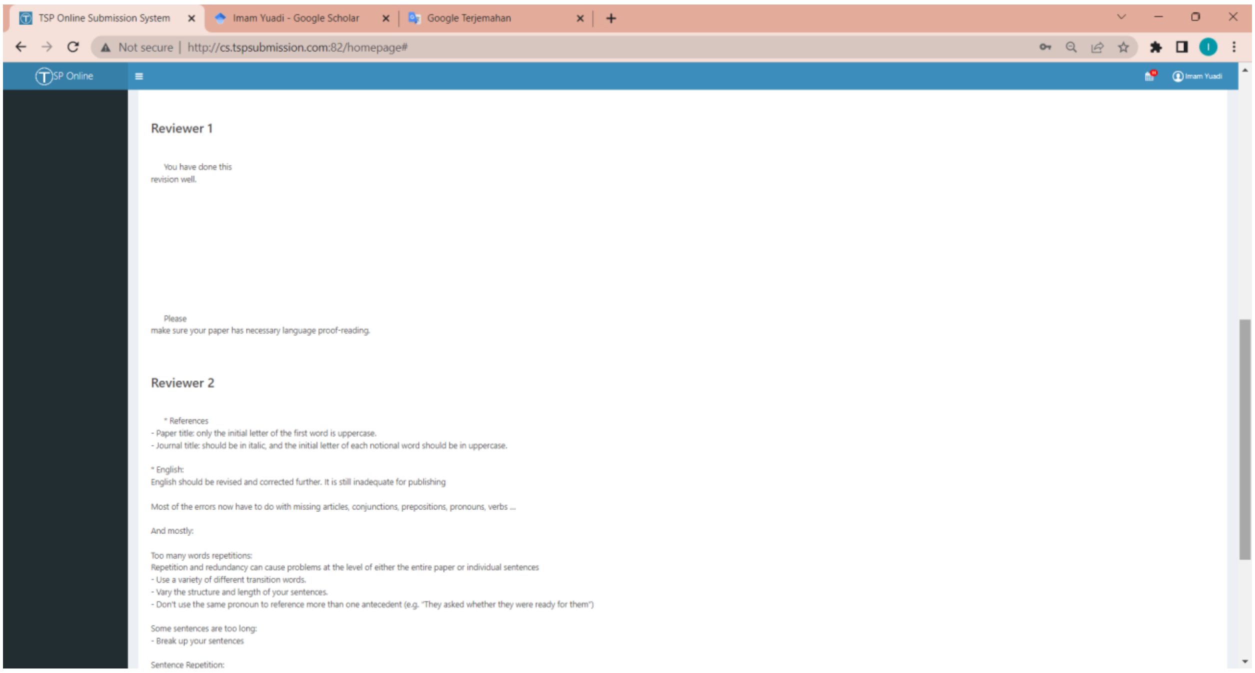
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You have done this
revision well.

Please
make sure your paper has necessary language proof-reading.

Reviewer 2

* References
- Paper title: only the initial letter of the first word is uppercase.
- Journal title: should be in italic, and the initial letter of each notional word should be in uppercase.

* English:
English should be revised and corrected further. It is still inadequate for publishing

Most of the errors now have to do with missing articles, conjunctions, prepositions, pronouns, verbs ...

And mostly:

Too many words repetitions:
Repetition and redundancy can cause problems at the level of either the entire paper or individual sentences
- Use a variety of different transition words.
- Vary the structure and length of your sentences.
- Don't use the same pronoun to reference more than one antecedent (e.g. "They asked whether they were ready for them")

Some sentences are too long:
- Break up your sentences

Sentence Repetition:

Selengkapnya:

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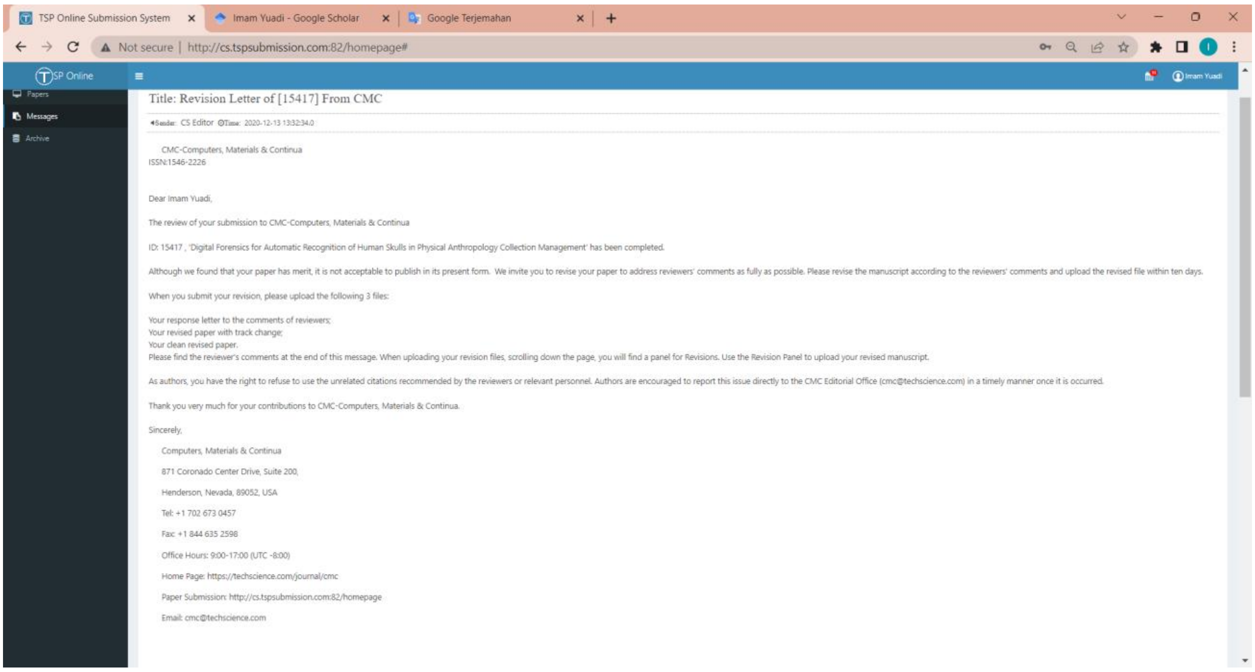
Some sentences are too long:
- Break up your sentences

Sentence Repetition:
- Avoid repetition at the sentence level
- Avoid sentences that restate the main point of the previous sentence.
- Don’t restate points you’ve already made.

Tips for avoiding the most common forms of repetition:
• Use a variety of different transition words
• Vary the structure and length of your sentences
• Don’t use the same pronoun to reference more than one antecedent (e.g. “They asked whether they were ready for them”)
• Avoid redundancies (e.g “In the year 2019” instead of “in 2019”)
• Don’t state the obvious (e.g. “The conclusion chapter contains the paper’s conclusions”)

5. CS Editor: Revision Letter of [15417] From CMC (3rd Round)



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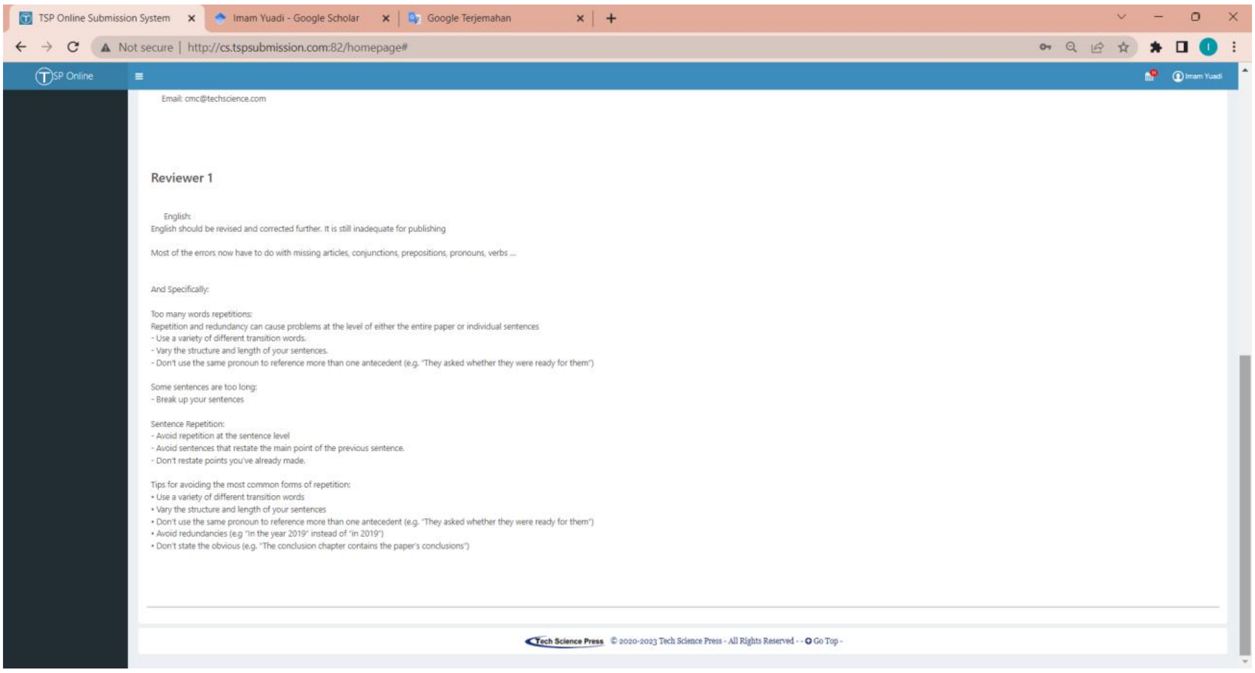

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Most of the errors now have to do with missing articles, conjunctions, prepositions, pronouns, verbs ...

And Specifically:

Too many words repetitions:
Repetition and redundancy can cause problems at the level of either the entire paper or individual sentences
- Use a variety of different transition words.
- Vary the structure and length of your sentences.
- Don't use the same pronoun to reference more than one antecedent (e.g. "They asked whether they were ready for them")

Some sentences are too long:
- Break up your sentences

Sentence Repetition:
- Avoid repetition at the sentence level
- Avoid sentences that restate the main point of the previous sentence.
- Don't restate points you've already made.

Tips for avoiding the most common forms of repetition:
• Use a variety of different transition words
• Vary the structure and length of your sentences
• Don't use the same pronoun to reference more than one antecedent (e.g. "They asked whether they were ready for them")
• Avoid redundancies (e.g "In the year 2019" instead of "in 2019")
• Don't state the obvious (e.g. "The conclusion chapter contains the paper's conclusions")

Selengkapnya:

Revision Letter of [15417] From CMC

CS Editor 2020-12-13 13:32:34.0

CMC-Computers, Materials & Continua
ISSN:1546-2226

Dear Imam Yuadi,

The review of your submission to CMC-Computers, Materials & Continua

ID: 15417 , 'Digital Forensics for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management' has been completed.

Although we found that your paper has merit, it is not acceptable to publish in its present form. We invite you to revise your paper to address reviewers’ comments as fully as possible. Please revise the manuscript according to the reviewers' comments and upload the revised file within ten days.

When you submit your revision, please upload the following 3 files:

Your response letter to the comments of reviewers;
Your revised paper with track change;
Your clean revised paper.
Please find the reviewer's comments at the end of this message. When uploading your revision files, scrolling down the page, you will find a panel for Revisions. Use the Revision Panel to upload your revised manuscript.

As authors, you have the right to refuse to use the unrelated citations recommended by the reviewers or relevant personnel. Authors are encouraged to report this issue directly to the CMC Editorial Office (cmc@techscience.com) in a timely manner once it is occurred.

Thank you very much for your contributions to CMC-Computers, Materials & Continua.

Sincerely,

Computers, Materials & Continua

871 Coronado Center Drive, Suite 200,

Henderson, Nevada, 89052, USA

Tel: +1 702 673 0457

Fax: +1 844 635 2598

Office Hours: 9:00-17:00 (UTC -8:00)

Home Page: https://techscience.com/journal/cmc

Paper Submission: http://cs.tspsubmission.com:82/homepage

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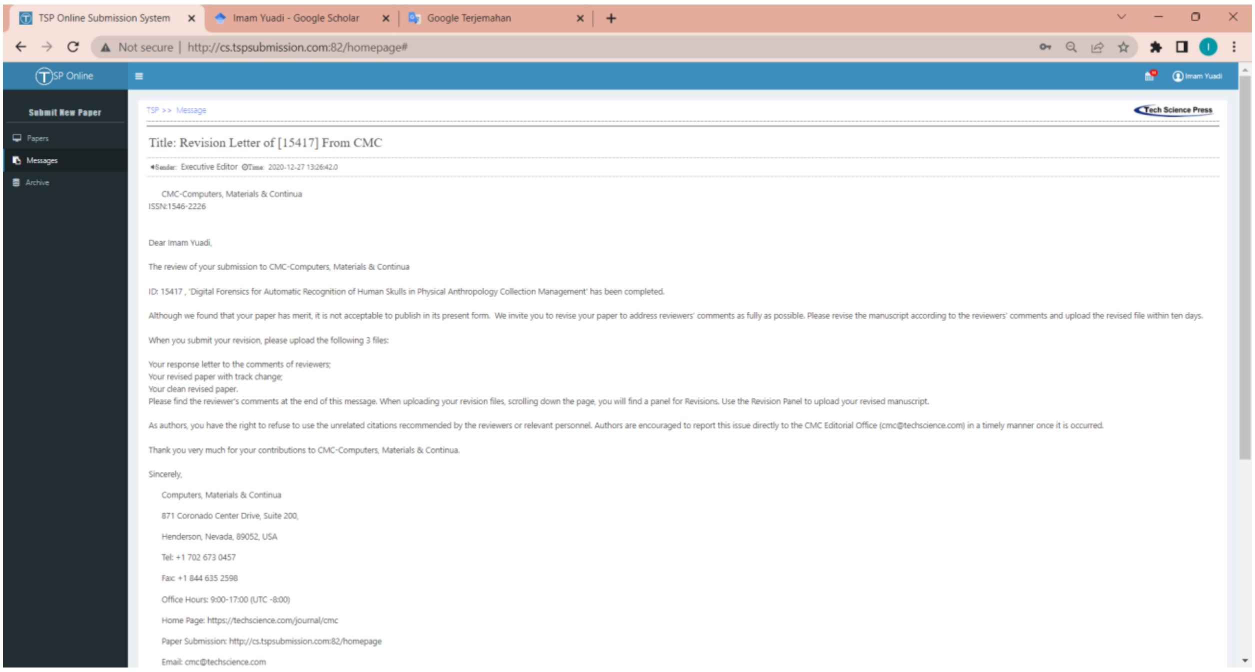
• Don’t state the obvious (e.g. “The conclusion chapter contains the paper’s conclusions”)

6. Executive Editor: Revision Letter of [15417] From CMC (4th Round)



TSP >> Message

Title: Revision Letter of [15417] From CMC

Sender: Executive Editor Time: 2020-12-27 13:26:42.0

CMC-Computers, Materials & Continua
ISSN:1546-2226

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ID: 15417 , 'Digital Forensics for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management' has been completed.

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Sincerely,

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Home Page: https://techscience.com/journal/cmc

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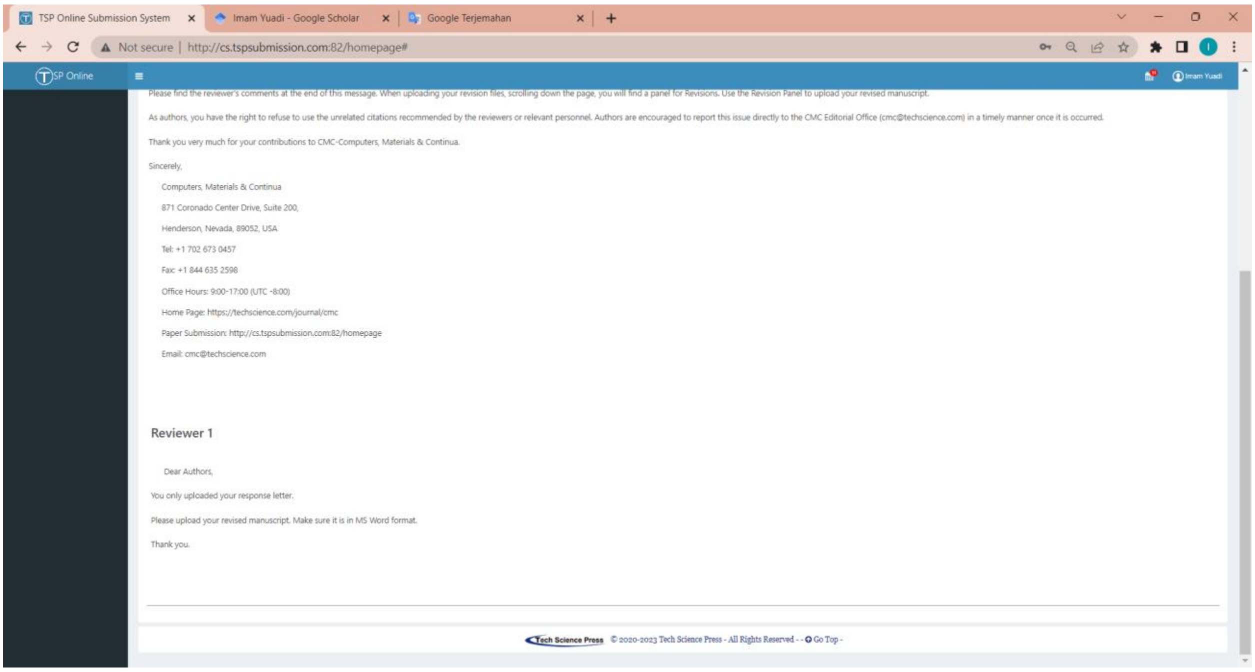

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Reviewer 1

Dear Authors,

You only uploaded your response letter.

Please upload your revised manuscript. Make sure it is in MS Word format.

Thank you.

Selengkapnya:

Revision Letter of [15417] From CMC

Executive Editor 2020-12-27 13:26:42.0

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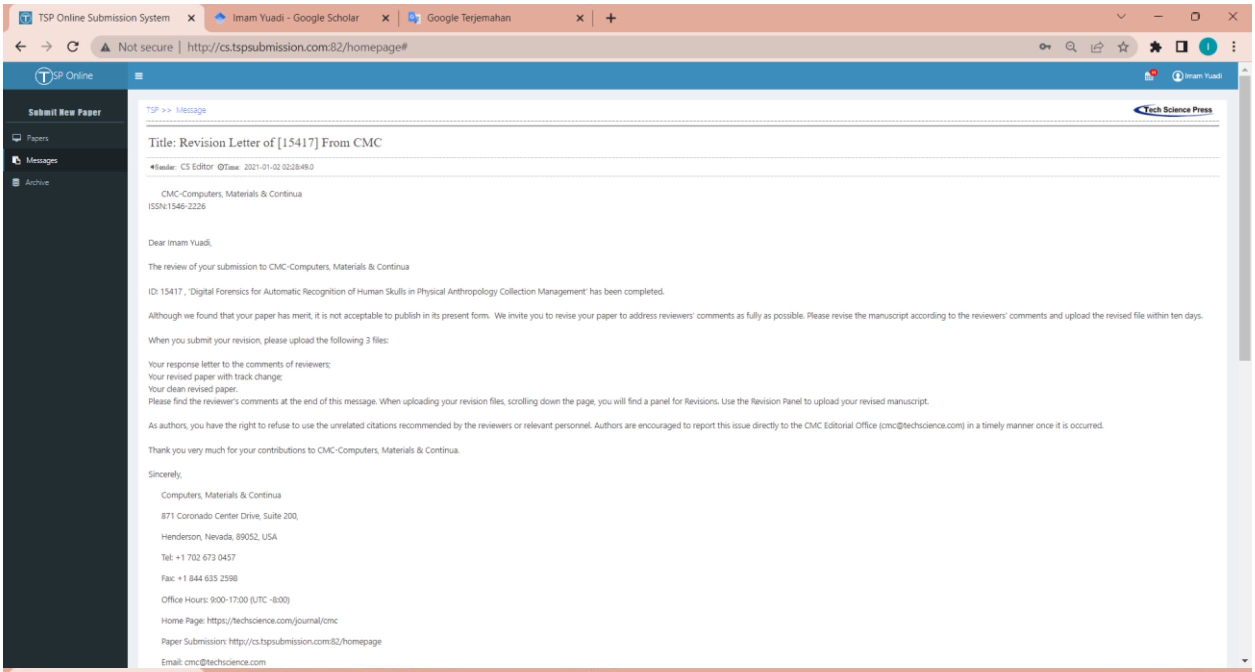
Thank you.

7. CS Editor: Revision Letter of [15417] From CMC (5th Round)



TSP >> Message

Title: Revision Letter of [15417] From CMC

Sender: CS Editor Time: 2021-01-02 02:28:49.0

CMC-Computers, Materials & Continua
ISSN:1546-2226

Dear Imam Yuadi,

The review of your submission to CMC-Computers, Materials & Continua

ID: 15417 , 'Digital Forensics for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management' has been completed.

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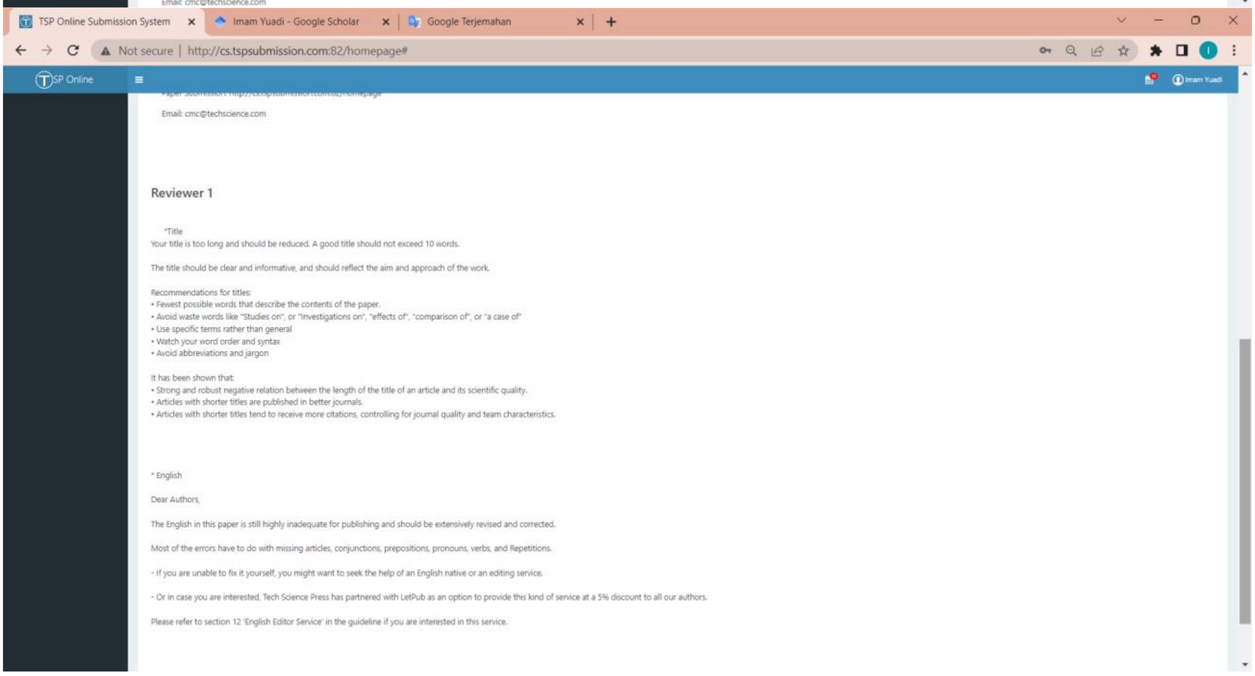

Email: cmc@techscience.com

Reviewer 1

*Title
Your title is too long and should be reduced. A good title should not exceed 10 words.

The title should be clear and informative, and should reflect the aim and approach of the work.

Recommendations for titles:
• Fewest possible words that describe the contents of the paper.
• Avoid waste words like "Studies on", or "Investigations on", "effects of", "comparison of", or "a case of"
• Use specific terms rather than general
• Watch your word order and syntax
• Avoid abbreviations and jargon

It has been shown that:
• Strong and robust negative relation between the length of the title of an article and its scientific quality.
• Articles with shorter titles are published in better journals.
• Articles with shorter titles tend to receive more citations, controlling for journal quality and team characteristics.

* English

Dear Authors,

The English in this paper is still highly inadequate for publishing and should be extensively revised and corrected.

Most of the errors have to do with missing articles, conjunctions, prepositions, pronouns, verbs, and Repetitions.

- If you are unable to fix it yourself, you might want to seek the help of an English native or an editing service.

- Or in case you are interested, Tech Science Press has partnered with LetPub as an option to provide this kind of service at a 5% discount to all our authors.

Please refer to section 12 'English Editor Service' in the guideline if you are interested in this service.

Selengkapnya:

Revision Letter of [15417] From CMC

CS Editor 2021-01-02 02:28:49.0

CMC-Computers, Materials & Continua
ISSN:1546-2226

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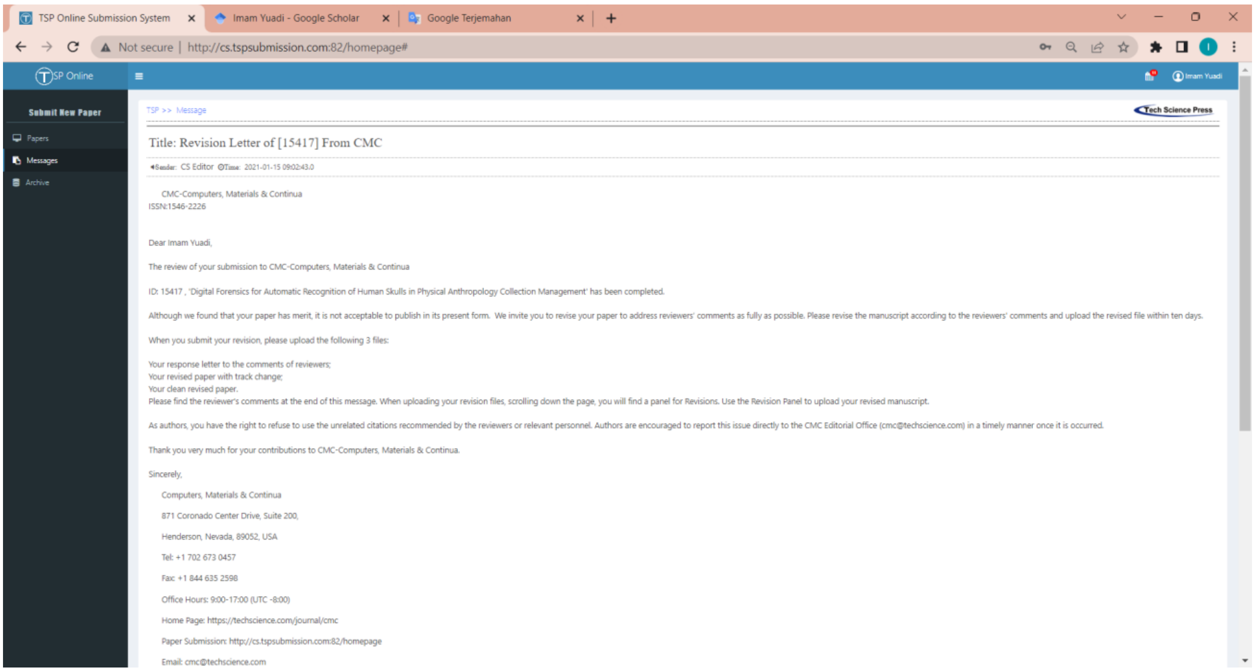
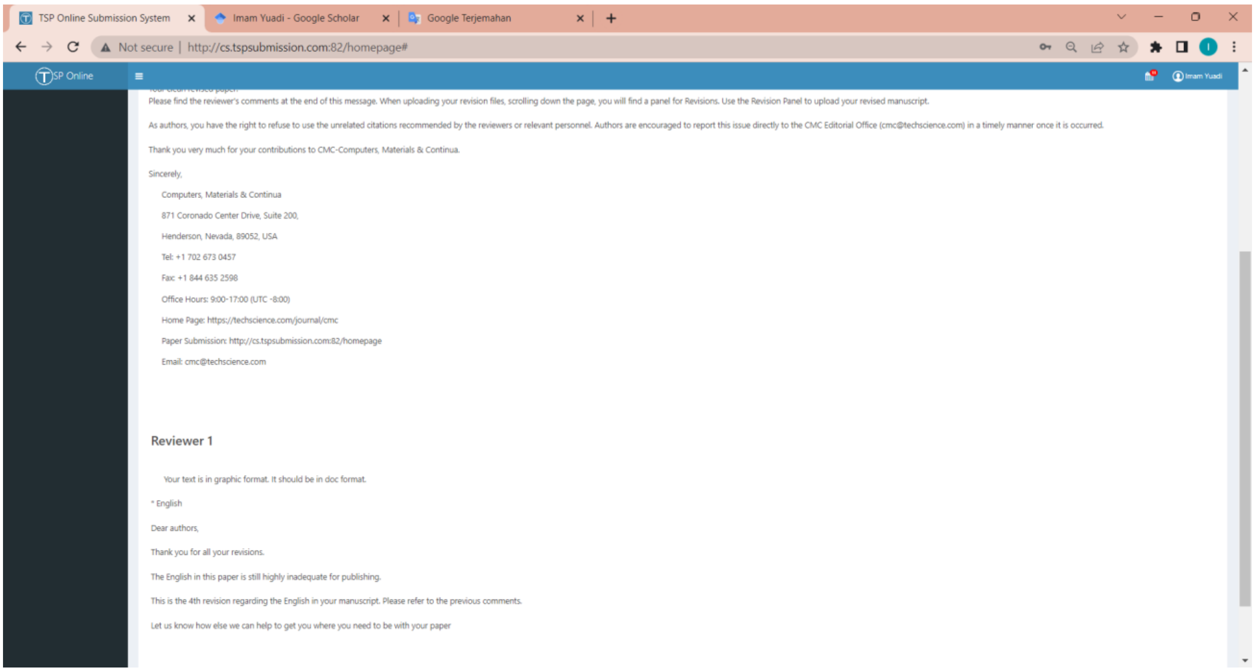
8. CS Editor: Revision Letter of [15417] From CMC (6th Round)





Selengkapnya:

Revision Letter of [15417] From CMC

CS Editor 2021-01-15 09:02:43.0

CMC-Computers, Materials & Continua
ISSN:1546-2226

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Email: cmc@techscience.com

Reviewer 1

Your text is in graphic format. It should be in doc format.

* English

Dear authors,

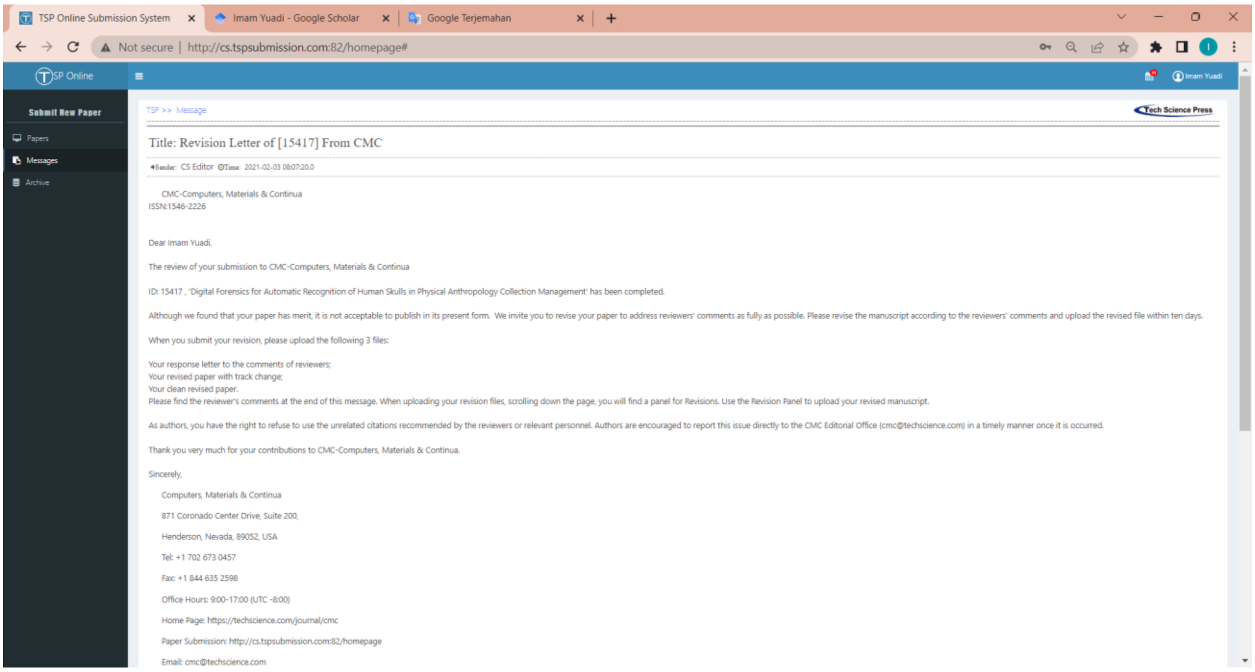
Thank you for all your revisions.

The English in this paper is still highly inadequate for publishing.

This is the 4th revision regarding the English in your manuscript. Please refer to the previous comments.

Let us know how else we can help to get you where you need to be with your paper

9. CS Editor: Revision Letter of [15417] From CMC (7^{th} Round)



Title: Revision Letter of [15417] From CMC

Sender: CS Editor Time: 2021-02-03 08:07:20.0

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ISSN:1546-2226

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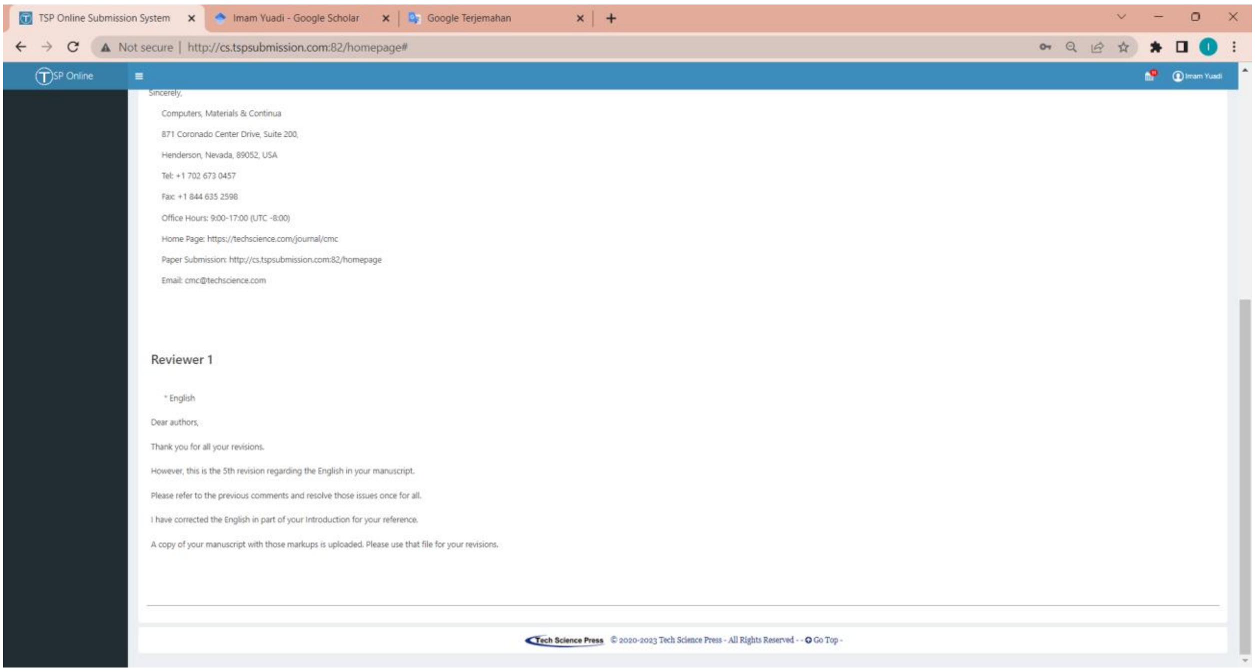

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Email: cmc@techscience.com

Reviewer 1

* English

Dear authors,

Thank you for all your revisions.

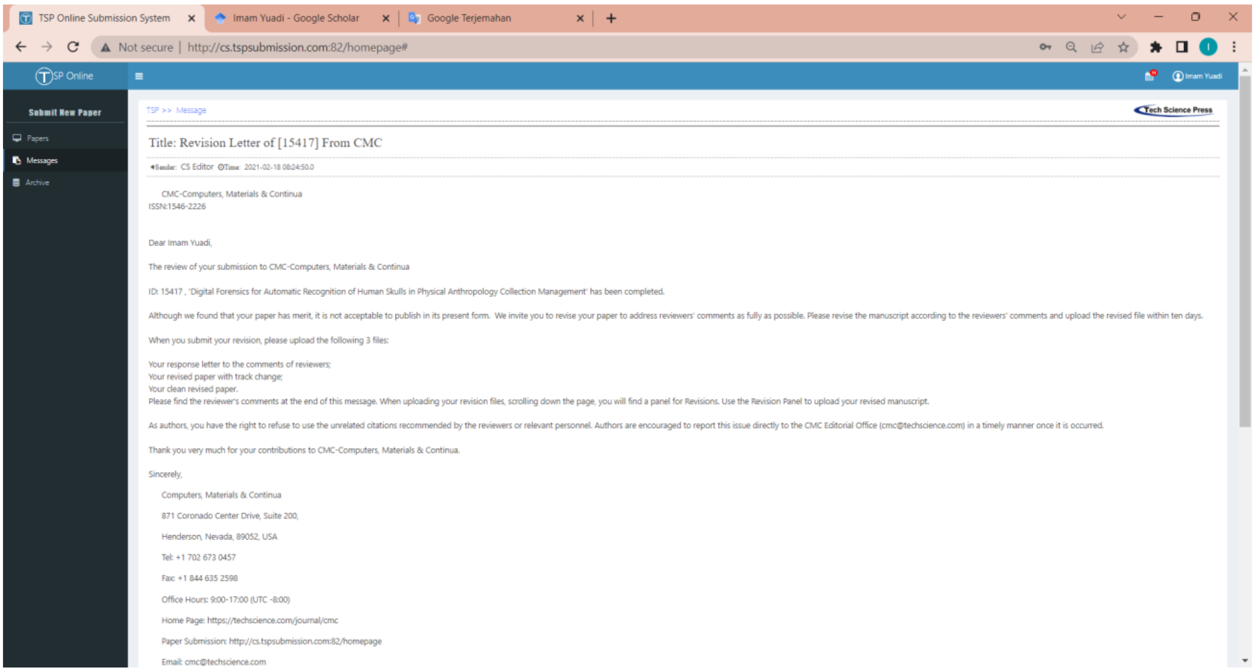
However, this is the 5th revision regarding the English in your manuscript.

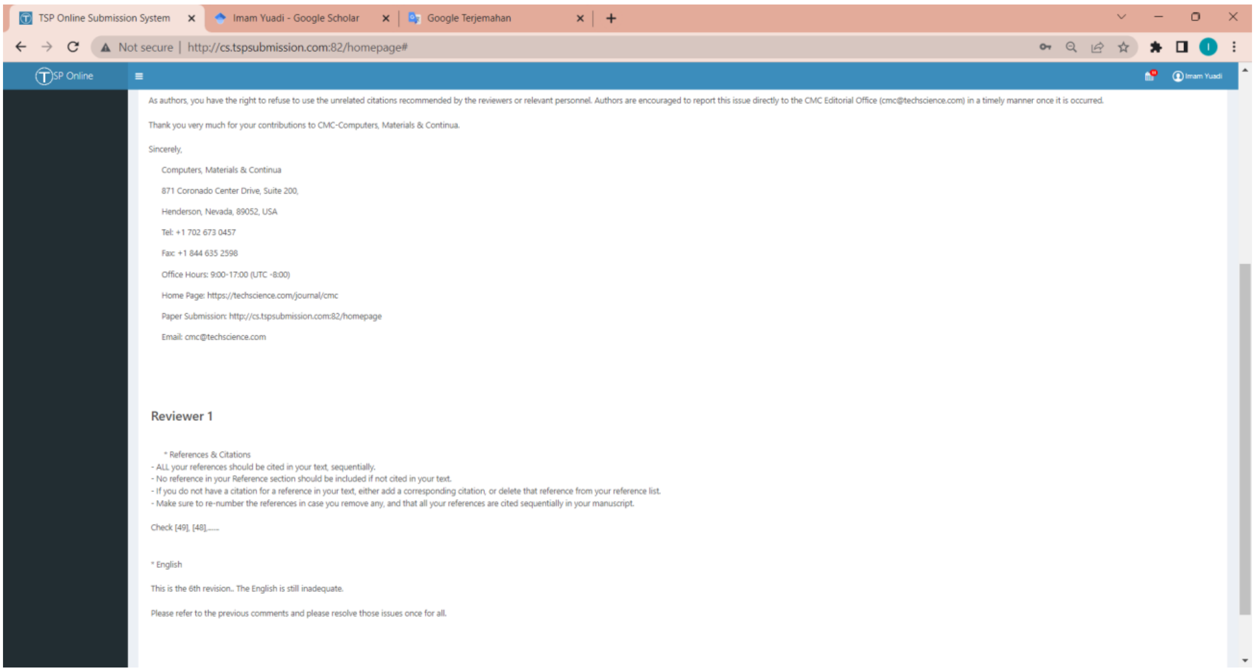
Please refer to the previous comments and resolve those issues once for all.

I have corrected the English in part of your Introduction for your reference.

A copy of your manuscript with those markups is uploaded. Please use that file for your revisions.

10. CS Editor: Revision Letter of [15417] From CMC (8th Round)





Selengkapnya:

Revision Letter of [15417] From CMC

CS Editor 2021-02-18 08:24:50.0

CMC-Computers, Materials & Continua
ISSN:1546-2226

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Reviewer 1

* References & Citations
- ALL your references should be cited in your text, sequentially.
- No reference in your Reference section should be included if not cited in your text.
- If you do not have a citation for a reference in your text, either add a corresponding citation, or delete that reference from your reference list.
- Make sure to re-number the references in case you remove any, and that all your references are cited sequentially in your manuscript.

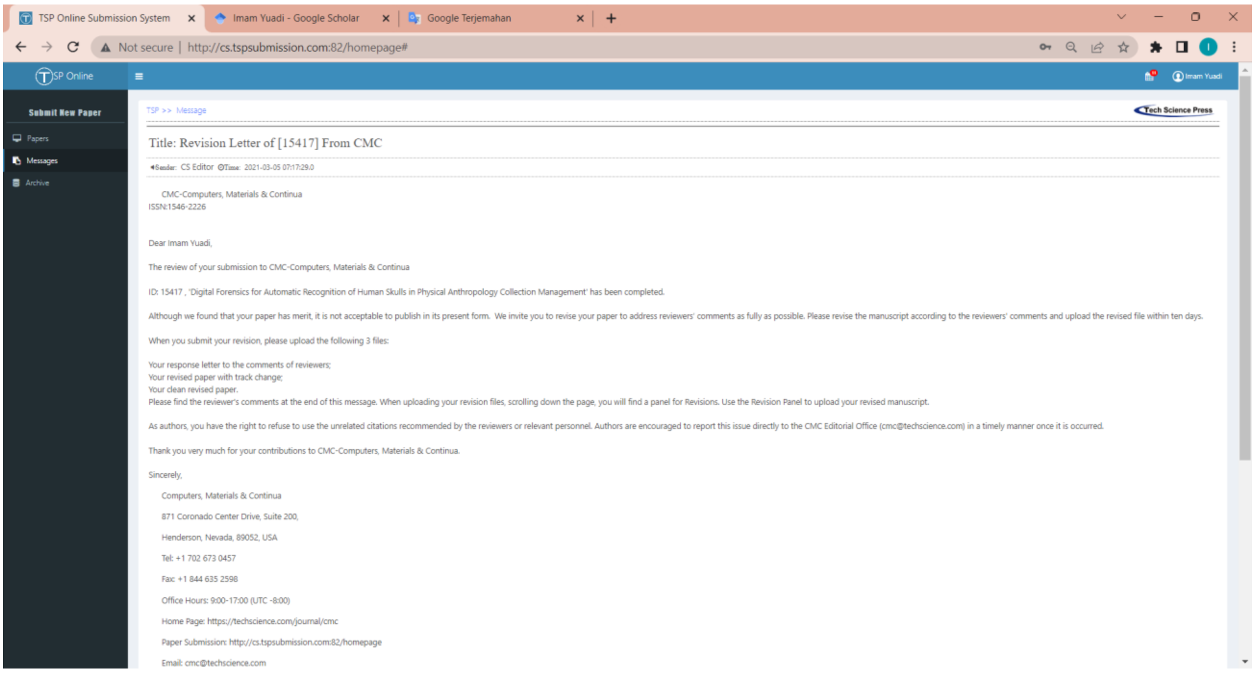
Check [49], [48],……

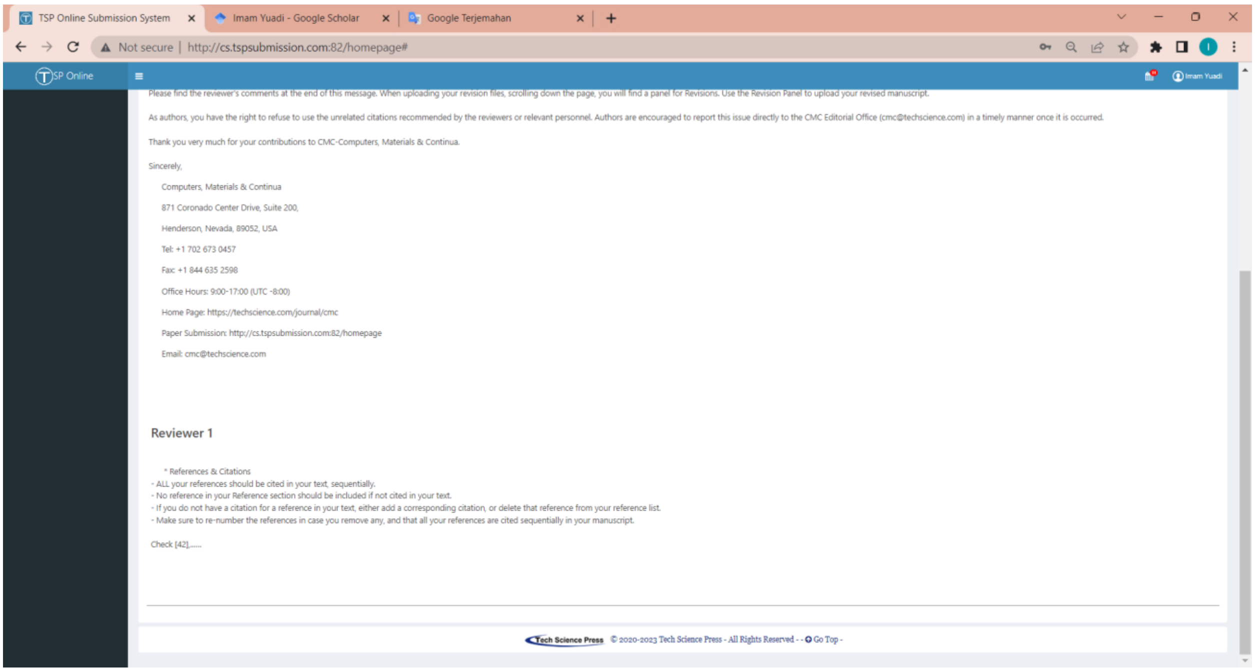
* English

This is the 6th revision.. The English is still inadequate.

Please refer to the previous comments and please resolve those issues once for all.

11. CS Editor: Revision Letter of [15417] From CMC (9th Round)





Selengkapnya:

Revision Letter of [15417] From CMC

CS Editor 2021-03-05 07:17:29.0

CMC-Computers, Materials & Continua
ISSN:1546-2226

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Reviewer 1

* References & Citations
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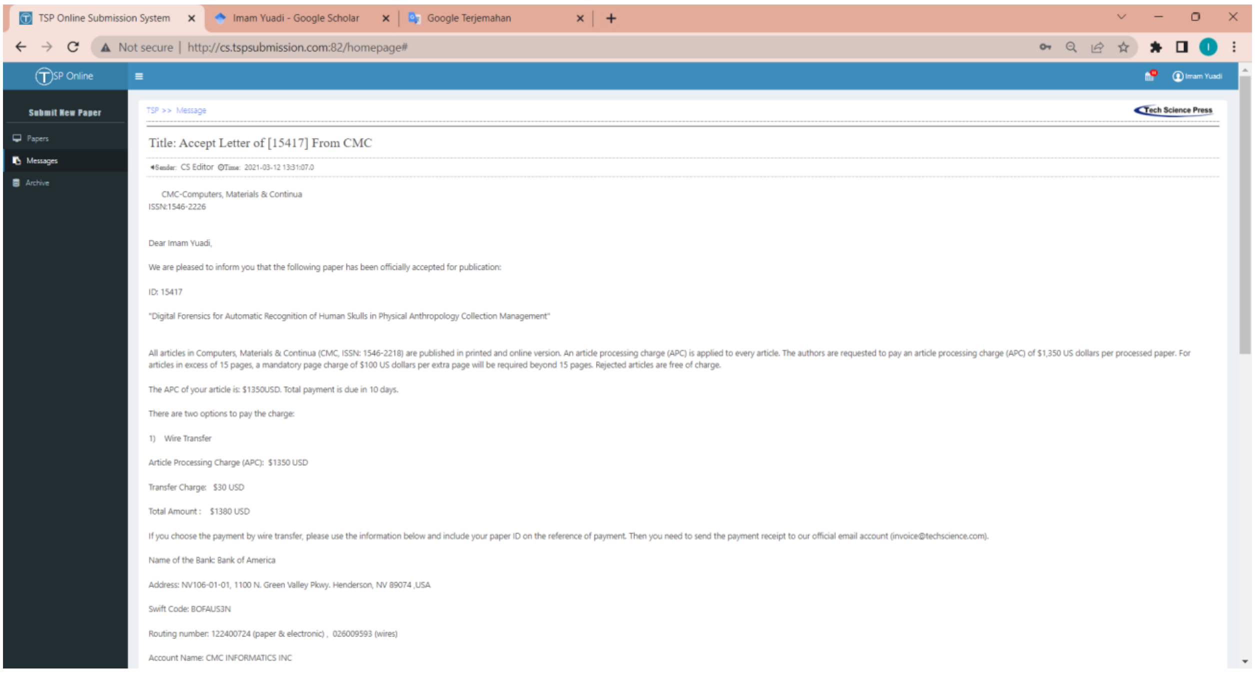
- Make sure to re-number the references in case you remove any, and that all your references are cited sequentially in your manuscript.

Check [42],……

12. CS Editor: Accept Letter of [15417] From CMC (10th Round)



Title: Accept Letter of [15417] From CMC

Sender: CS Editor Time: 2021-03-12 13:31:07.0

CMC-Computers, Materials & Continua
ISSN:1546-2226

Dear Imam Yuadi,

We are pleased to inform you that the following paper has been officially accepted for publication:

ID: 15417

"Digital Forensics for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management"

All articles in Computers, Materials & Continua (CMC, ISSN: 1546-2218) are published in printed and online version. An article processing charge (APC) is applied to every article. The authors are requested to pay an article processing charge (APC) of $1,350 US dollars per processed paper. For articles in excess of 15 pages, a mandatory page charge of $100 US dollars per extra page will be required beyond 15 pages. Rejected articles are free of charge.

The APC of your article is: $1350USD. Total payment is due in 10 days.

There are two options to pay the charge:

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Article Processing Charge (APC): $1350 USD

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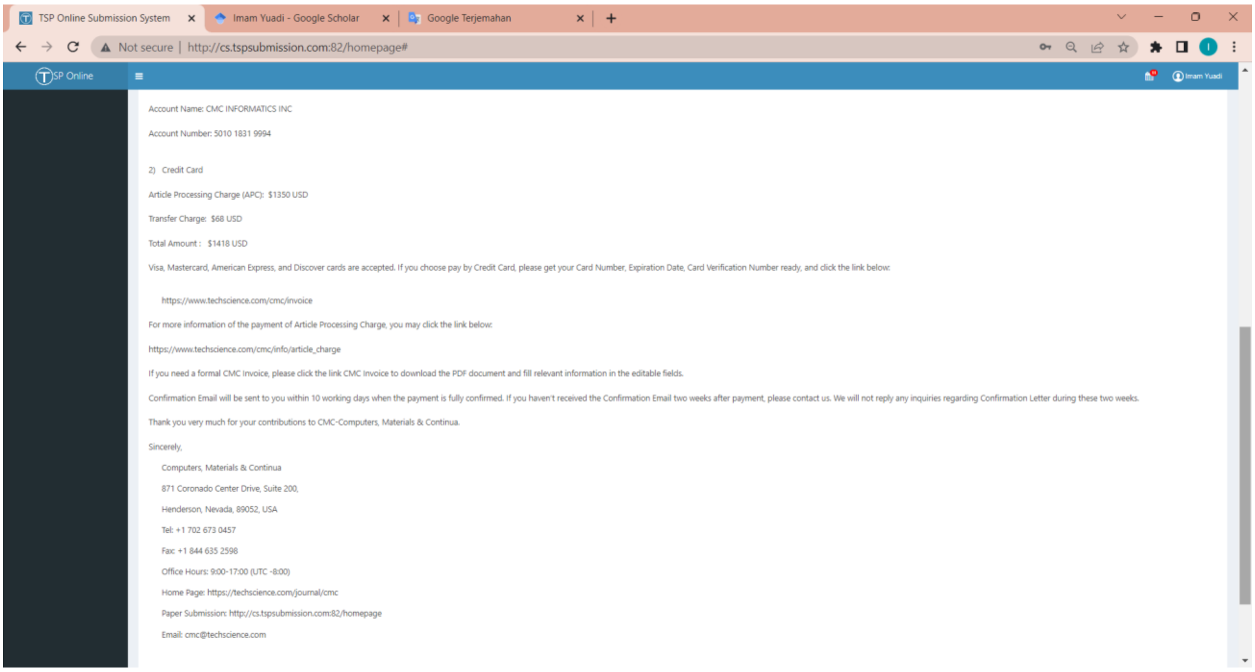

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Confirmation Email will be sent to you within 10 working days when the payment is fully confirmed. If you haven't received the Confirmation Email two weeks after payment, please contact us. We will not reply any inquiries regarding Confirmation Letter during these two weeks.

Thank you very much for your contributions to CMC-Computers, Materials & Continua.

Sincerely,

Computers, Materials & Continua

871 Coronado Center Drive, Suite 200,

Henderson, Nevada, 89052, USA

Tel: +1 702 673 0457

Fax: +1 844 635 2598

Office Hours: 9:00-17:00 (UTC -8:00)

Home Page: https://techscience.com/journal/cmc

Paper Submission: http://cs.tspsubmission.com:82/homepage

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Accept Letter of [15417] From CMC

CS Editor 2021-03-12 13:31:07.0

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For more information of the payment of Article Processing Charge, you may click the link below:

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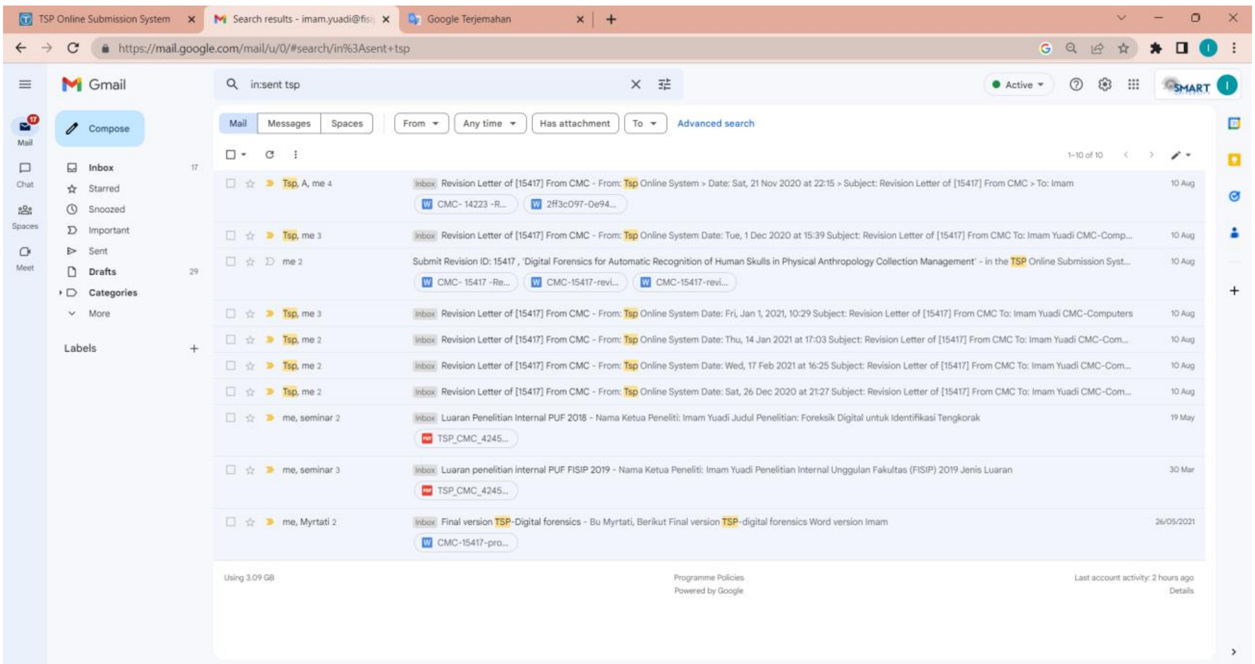
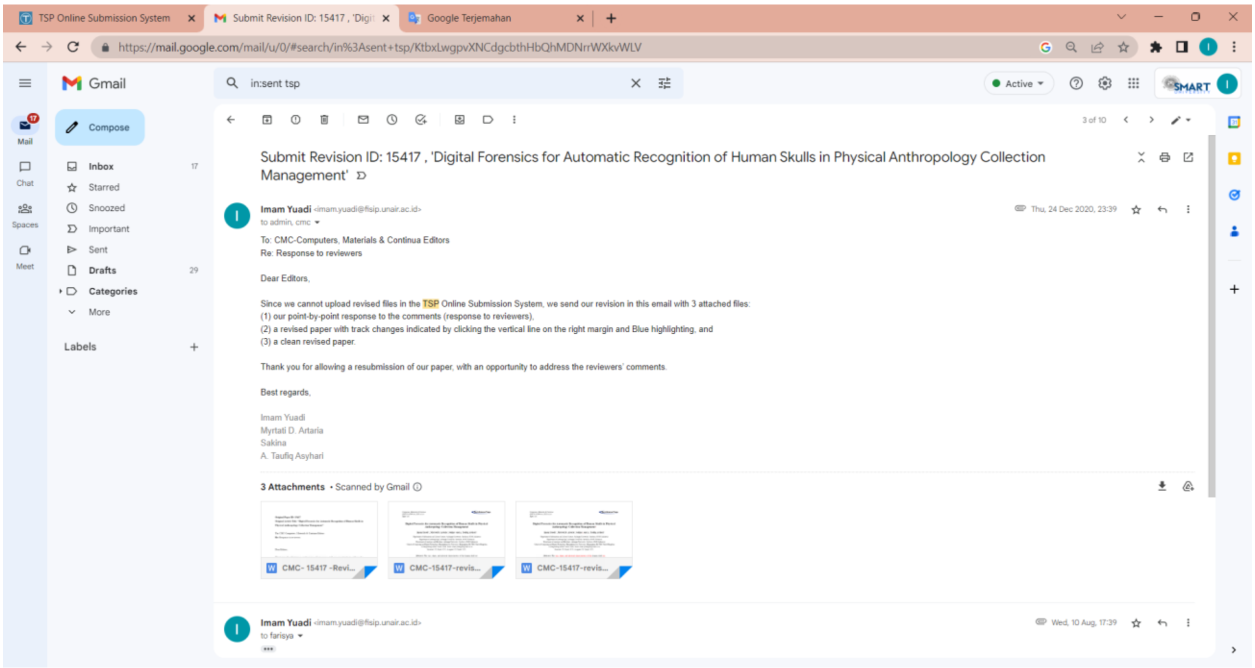
Paper Submission: http://cs.tspsubmission.com:82/homepage

Email: cmc@techscience.com

Jawaban Reviewer:

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Sent
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Categories
More
Labels
3 of 10
Submit Revision ID: 15417 , 'Digital Forensics for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management'
Imam Yuadi <imam.yuadi@fisip.unair.ac.id>
to admin, cmc
Thu, 24 Dec 2020, 23:39
To: CMC-Computers, Materials & Continua Editors
Re: Response to reviewers
Dear Editors,
Since we cannot upload revised files in the TSP Online Submission System, we send our revision in this email with 3 attached files:
(1) our point-by-point response to the comments (response to reviewers),
(2) a revised paper with track changes indicated by clicking the vertical line on the right margin and Blue highlighting, and
(3) a clean revised paper.
Thank you for allowing a resubmission of our paper, with an opportunity to address the reviewers' comments.
Best regards,
Imam Yuadi
Myrtati D. Artaria
Sakina
A. Taufiq Asyhari
3 Attachments • Scanned by Gmail
CMC- 15417 -Revi...
CMC-15417-revis...
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Imam Yuadi <imam.yuadi@fisip.unair.ac.id>
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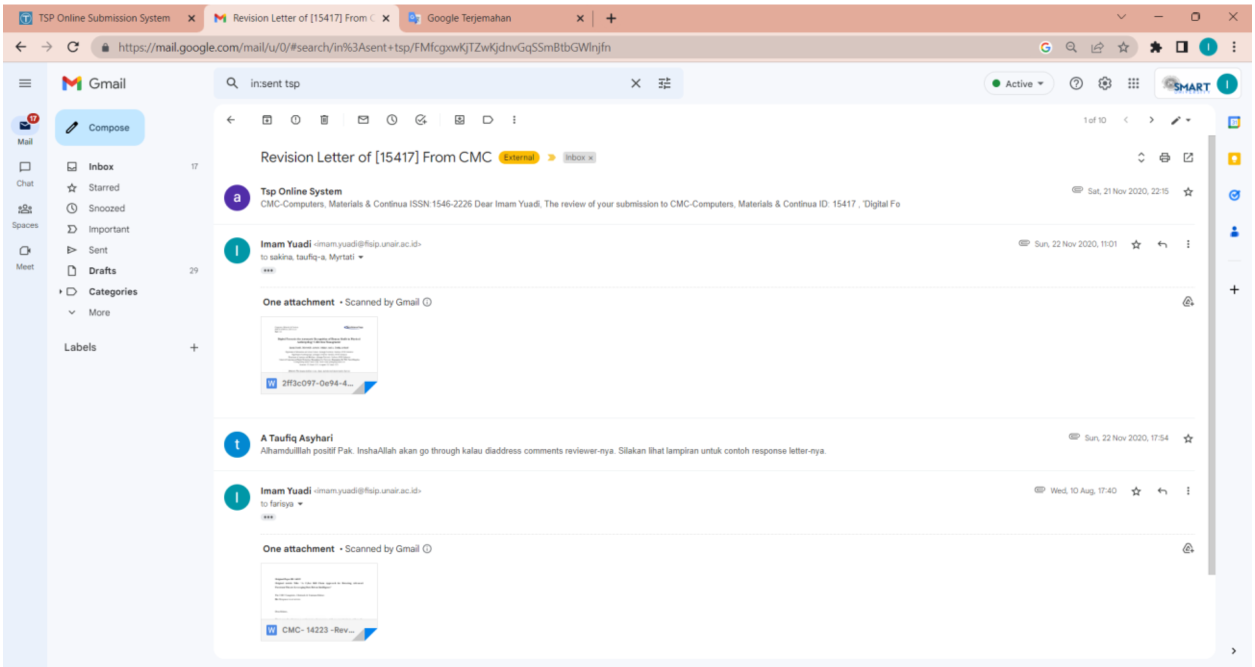
Wed, 10 Aug, 17:39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Snoozed
Important
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Drafts 29
Categories
More
Labels
1 of 10
Revision Letter of [15417] From CMC
External
Inbox
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Sat, 21 Nov 2020, 22:15
CMC-Computers, Materials & Continua ISSN:1546-2226 Dear Imam Yuadi, The review of your submission to CMC-Computers, Materials & Continua ID: 15417 , 'Digital Fo
Imam Yuadi <imam.yuadi@fisip.unair.ac.id>
to sakina, taufiq-a, Myrtati
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Alhamduilllah positif Pak. InshaAllah akan go through kalau diaddress comments reviewer-nya. Silakan lihat lampiran untuk contoh response letter-nya.
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Wed, 10 Aug, 17:40
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CMC- 14223 -Rev...

CMC- 15417 -Reviewers comments and Authors Reponses

Original Paper ID: 15417

Original Article Title: "Digital Forensics for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management"

To: CMC-Computers, Materials & Continua Editors

Re: Response to reviewers

Dear Editors,

Thank you for allowing a resubmission of our paper, with an opportunity to address the reviewers' comments.

We are uploading (a) our point-by-point response to the comments (below) (response to reviewers), (b) a revised paper with **track changes** indicated by Blue highlighting, and (c) a **clean revised paper**.

Best regards,

Imam Yuadi

Myrtati D. Artaria

Sakina

A. Taufiq Asyhari

Editor's Evaluation and Comment

The review of your submission to CMC-Computers, Materials & Continua

ID: 15417 , 'Digital Forensics for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management' has been completed.

Although we found that your paper has merit, it is not acceptable to publish in its present form. We invite you to revise your paper to address reviewers' comments as fully as possible. Please revise the manuscript according to the reviewers' comments and upload the revised file within ten days.

When you submit your revision, please upload the following 3 files:

Your response letter to the comments of reviewers;

Your revised paper with track change;

Your clean revised paper.

Please find the reviewer's comments at the end of this message. When uploading your revision files, scrolling down the page, you will find a panel for Revisions. Use the Revision Panel to upload your revised manuscript.

As authors, you have the right to refuse to use the unrelated citations recommended by the reviewers or relevant personnel. Authors are encouraged to report this issue directly to the CMC Editorial Office (cmc@techscience.com) in a timely manner once it is occurred.

Thank you very much for your contributions to CMC-Computers, Materials & Continua

Author response:

Dear Editor,

Thank you very much for your time in evaluating this manuscript and the opportunity for revising and resubmitting our paper after revision. Please see the following as our responses to the comments raised by the reviewers. I sincerely hope they are satisfactory.

Reviewer#1, Comment #1

This paper reports a study that identified a human skull using an automatic classification approach that uses a support vector machine and different feature extraction methods such as Gray-level Co-occurrence Matrix features, Gabor features, Fractal features, Discrete Wavelet Transform, and features combination. It is a well written paper that follows a typical scholarly format. The title, the abstract and the keywords suit well with the overall contents of the article. The introduction is well composed highlighting the latest development of the research topic and the research gap that the study intended to address. Drawing upon the studies on face recognition based on photos, this study emulates similar approach by focusing on the photos of human skulls. The review of the literature was adequate to provide a supportive background of the study. The materials and method section was also well described, leaving no room for criticism. The findings of the study were compared with previous studies that used different algorithm. The higher degree of accuracy of the findings as compared to other algorithm is perhaps the most significant contribution of the study.

Author response:

We thank you for your effort in evaluating this paper by going through the details of this work.

We are pleased to hear your positive evaluation of the overall contents of this manuscript.

Reviewer#1, Comment #2

The only shortcoming of the article, is the lack of highlighting the limitation of the present technique and offering research opportunities for those interested to further extend this current work. On the basis of this comment, I suggest the article should be accept as it is or at at least address the aforementioned shortcomings.

Author response:

We appreciate this feedback, which helps us further improve the manuscript.

To account for your suggestion, we have made the following modifications to the manuscript. For the limitation of this study, we have written on Section 4.5 as follows.

> The limitation of this study can be identified from the use of the same digital camera brand to ensure that the resolution is the same for capturing skull images. We are also constrained with the seven different angles to perform comparison between skulls with mandible and skulls without mandible. Due to the difficulty of finding human skulls as the research object, this study focuses on the classification of 24 skulls, which are all in incomplete conditions, especially for the teeth attached to the skull.

For future direction, we have incorporated this briefly in Conclusion.

> We can identify several future directions for research related to skulls identification. For future work, it will be necessary to optimize the combined feature extraction and classification method and to explore other feature extraction techniques and classification methods for performance comparisons. The use of more skulls data using the CNN method can be the main focus for future research. Furthermore, determining the age and gender of the skulls will greatly assist researchers in identifying humans who have disappeared due to natural disasters and criminal events.

Reviewer#2, Comment # 1:

This paper proposed an automatic human skull classification approach that uses a support vector machine and feature extraction methods for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management. The authors did a good job in connecting to some relevant literature and explaining what was performed in the study. However, there are a few major issues that were not adequately addressed:

1. The framework of the digital forensics process in Figure 2 which is described by the authors is unclear and needs to be revised, especially in using the font size, it should be enlarged so that it is easier to read.

Author response:

We really appreciate your effort in reading through our paper and are grateful for your positive feedback. We have now revised Figure 2 with hopefully clearer texts as follow.

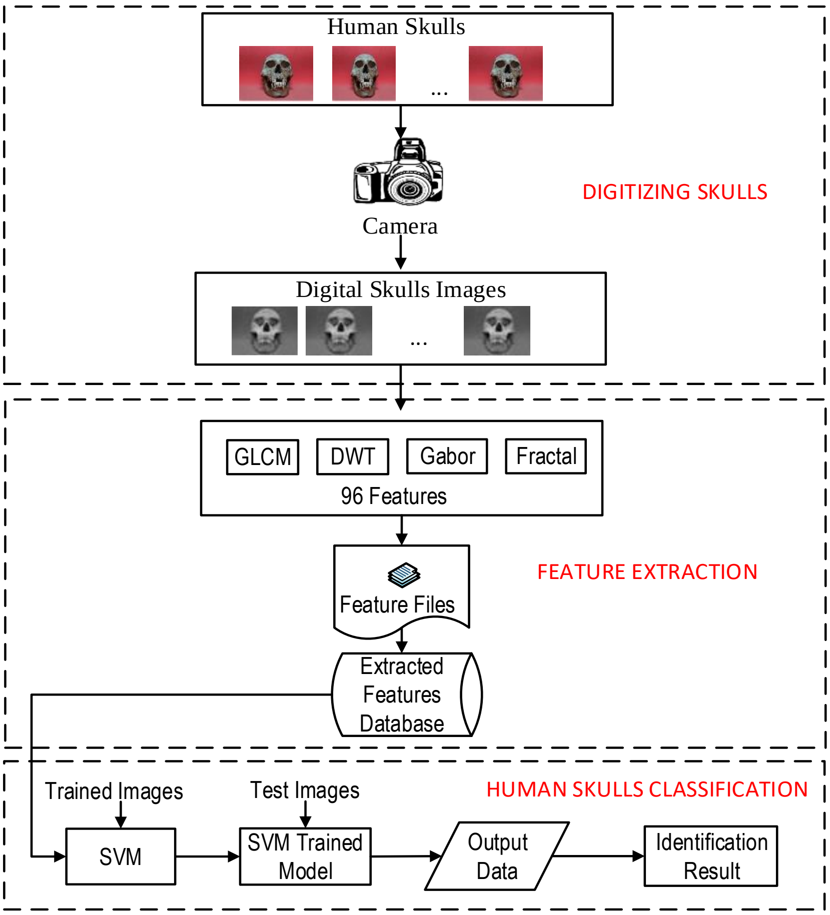


Figure 2: Framework used for digital forensics in investigating characteristics of human skulls

Reviewer#2, Comment # 2:

2. Based on the description in paragraph experiment III, the contents of column table IV should be camera resolution: 2, 4, and 9 MP. And the experiment named the name of the experiment should be "DIFFERENT RESOLUTIONS FOR SKULL CLASSIFICATION"

Author response:

Thank you very much for your correction. We have revised the Table 4 Accuracy prediction (%) for different resolutions and the subtitle for Experiment III as different resolutions for skull classification.

Reviewer#2, Comment # 3 (a):

Many typos in the manuscript should be revised. For examples:

a) equation 1: brackets

Author response:

Thank you for raising this concern. We have followed the equation formatting of this journal, including the use of brackets.

Reviewer#2, Comment # 3 (b):

b) page 6: Inspired by "thes" works, to extract human skull images ... ==> the

Author response:

Thank you for raising this concern. We have corrected this misprint.

Reviewer#2, Comment # 3 (c):

c) page 6 & 10: "Tab. I" detail the 360 processed sample images for .... ==> Table 1 ; Tab. 4 à Table 4

Author response:

Thank you for this correction. We revised Table Labels and Captions based on the format of this journal.

Furthermore the use of the short forms "Tab. 1" and "Tab. 4" has followed the formatting and style requirement of this journal.

Reviewer#2, Comment # 3 (d):

Many typos in the manuscript should be revised. For examples:

d) page 10: The classifications of skulls with mandibles tabulated in "Table II" have different accuracies according to .... Table II à Table 2 ...

Author response:

Thank you for your correction. We have revised the table name by using the format of this journal.

Reviewer#3, Comment # 1:

Please revise your paper in the following parts.

1. Your paper has 16 pages, please shorten it within 15 pages. If you are willing to pay the processing fee for the extra pages beyond 15 pages, you may not shorten your paper within 15 pages.

The authors are requested to be committing to pay an article processing charge (APC) of $1,000 US dollars per processed paper currently. For articles in excess of 15 pages, a mandatory page charge of $100 US dollars per extra page will be required beyond

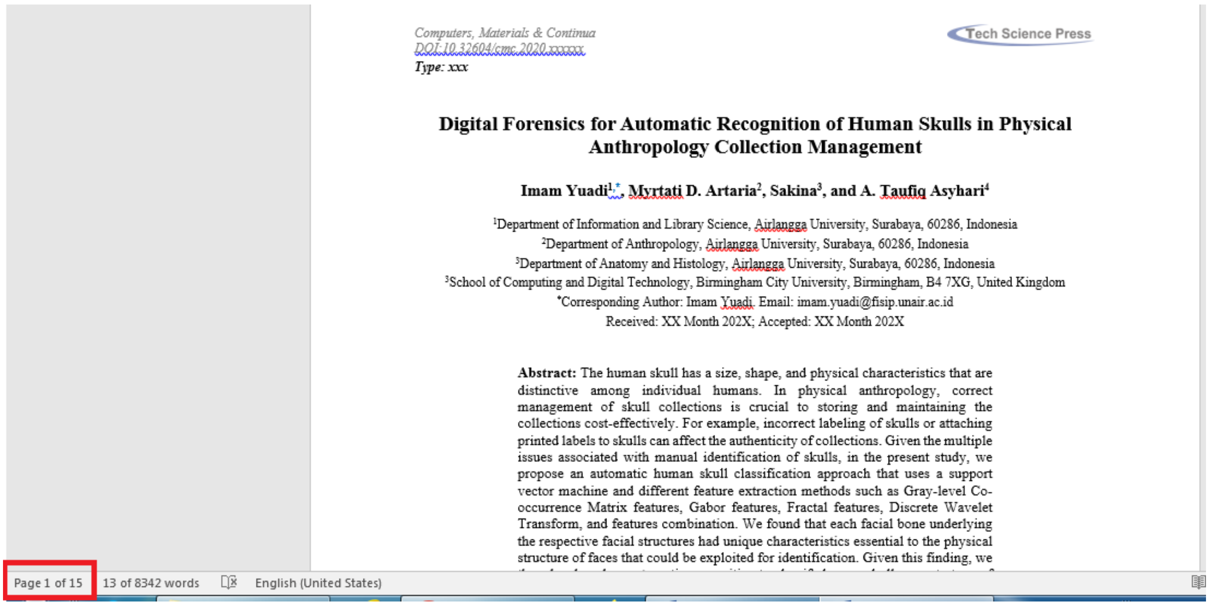
15 pages.

Author response:

Thank you for this comment and reminding us about this page limit. We have made sure that the revised paper is within the page limit of 15.

We understand that MS Word documents may generally open differently over different platforms and operating systems. We have tested the current paper over several Windows platforms, which consistently showed the total number of pages equal to 15.

Please find below a screenshot that shows the total number of pages is 15.



Computers, Materials & Continua
DOI:10.32604/cmc.2020.xxxxxx
Type: xxx

Tech Science Press

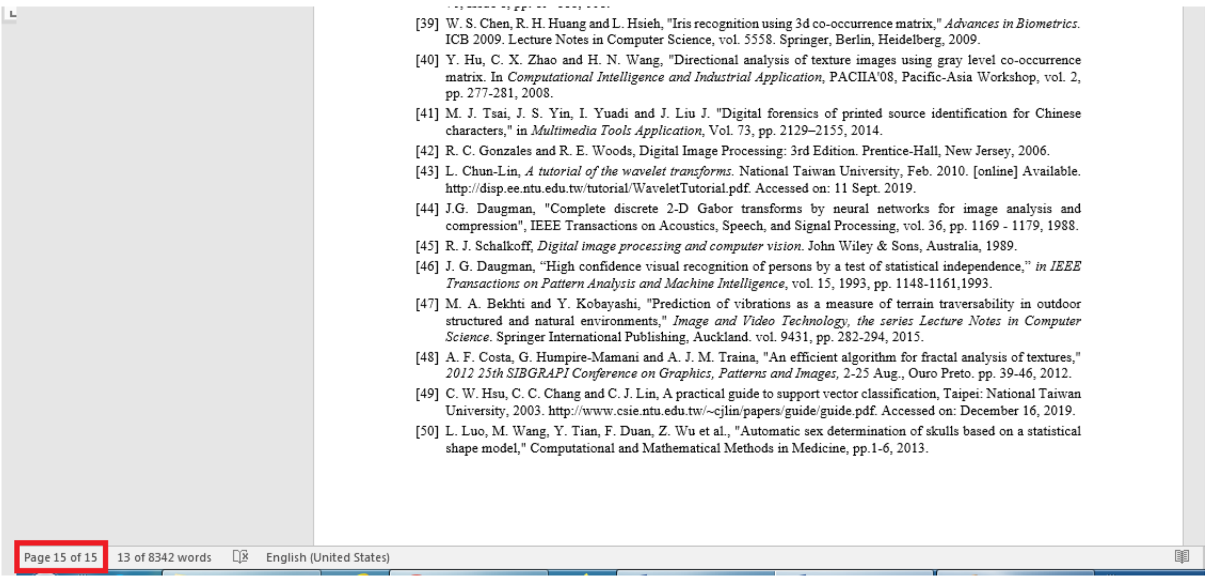
Digital Forensics for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management

Imam Yuadi[1,*], Myrtati D. Artaria[2], Sakina[3], and A. Taufiq Asyhari[4]

[1]Department of Information and Library Science, Airlangga University, Surabaya, 60286, Indonesia
[2]Department of Anthropology, Airlangga University, Surabaya, 60286, Indonesia
[3]Department of Anatomy and Histology, Airlangga University, Surabaya, 60286, Indonesia
[3]School of Computing and Digital Technology, Birmingham City University, Birmingham, B4 7XG, United Kingdom
*Corresponding Author: Imam Yuadi. Email: imam.yuadi@fisip.unair.ac.id
Received: XX Month 202X; Accepted: XX Month 202X

Abstract: The human skull has a size, shape, and physical characteristics that are distinctive among individual humans. In physical anthropology, correct management of skull collections is crucial to storing and maintaining the collections cost-effectively. For example, incorrect labeling of skulls or attaching printed labels to skulls can affect the authenticity of collections. Given the multiple issues associated with manual identification of skulls, in the present study, we propose an automatic human skull classification approach that uses a support vector machine and different feature extraction methods such as Gray-level Co-occurrence Matrix features, Gabor features, Fractal features, Discrete Wavelet Transform, and features combination. We found that each facial bone underlying the respective facial structures had unique characteristics essential to the physical structure of faces that could be exploited for identification. Given this finding, we

Page 1 of 15 | 13 of 8342 words | English (United States)



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Page 15 of 15 | 13 of 8342 words | English (United States)

Reviewer#3, Comment # 2:

2. The Corresponding Author of all the authors should be marked with superscript* after superscript number and a comma"," should be used to separate superscript number and superscript*.

Author response:

Thanks for your correction. We have followed this requirement and indicated in the revised manuscript.

Reviewer#3, Comment # 3:

3. Only the initial letter of the first keyword should be capitalized except Proper Nouns. Please use a semi-colon “ ; ” to separate each keyword.

Author response:

Thanks for your comment. We have followed this suggestion in the revised manuscript.

Reviewer#3, Comment # 4:

3. Your Citing References are in the wrong order.
Note: Citing References in the main text should be arranged in order from number [1].
E.g. In your paper, you cite Reference [27,

28] after Reference [2], you should cite Reference [3] after Reference [2], then you can cite Reference [3-28].

E.g. In your paper, you cite Reference [30-32] after Reference [27-28], you should cite Reference [29] after Reference [27-28], then you can cite Reference [30--32].

Author response:

Thanks for your suggestion. We have re-ordered the references in ascending order.

Reviewer#3, Comment # 5:

5. Regarding Headings including Level one, two and three headings, the initial letter of each notional word of the Headings should be capitalized. All the headings should be flushed to the left margin.

E.g.

In Section 1.2, this should be This.

Author response:

Thanks for your correction. The heading in this manuscript have been capitalized such as your comments.

Reviewer#3, Comment # 6:

6. Please add Conflicts of Interest before your references.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

Author response:

Thanks for your comment. We have added the Conflicts of Interest before the references of this paper.

Reviewer#3, Comment # 6a:

7. Most of your references are not in the right format, please use the CMC new format.

a. Regarding a paper title in a journal or a conference, only the initial letter of the first word except the Proper Nouns should be capitalized. E.g. Reference 1, 2, 12-16, 20-25, …, 50.

Author response:

Thanks for your correction. We have revised all the title journals or conferences on references such as your suggestion.

Reviewer#3, Comment # 6b:

b. There should be a word "and" between the last 2 authors or editors. There is no comma ","before the word "and". E.g. Reference 39-42.

Author response:

Thanks for your comment. We removed the comma before the "and" between the last two authors.

Reviewer#3, Comment # 6c:

c. Regarding authors, only the first five authors are listed as they appear. When more than five authors are listed, keep the first five authors and followed by et al. There is no comma ","before the word "et al.". There is no word "and" before the last author. E.g. Reference 16, 26, 28, 50.

Author response:

Thanks for your comment. We have revised several references that have more five author by keep the first five authors and followed by et al.

Reviewer#3, Comment # 6d:

d. And you need to provide the authors’ name, the paper title’s name, volume number, issue number, page number and published year as the format: vol. xx, no. xx, pp. xx-xx, published year. The published year should be put at the end of the reference. E.g. Reference 16.

Author response:

Thanks for your comment. We have corrected for this reference.

Editor’s Evaluation and Comment

The review of your submission to CMC-Computers, Materials & Continua

ID: 15417 , 'Digital Forensics for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management' has been completed.

Although we found that your paper has merit, it is not acceptable to publish in its present form. We invite you to revise your paper to address reviewers’ comments as fully as possible. Please revise the manuscript according to the reviewers' comments and upload the revised file within ten days.

When you submit your revision, please upload the following 3 files:

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Your clean revised paper.

Please find the reviewer's comments at the end of this message. When uploading your revision files, scrolling down the page, you will find a panel for Revisions. Use the Revision Panel to upload your revised manuscript.

As authors, you have the right to refuse to use the unrelated citations recommended by the reviewers or relevant personnel. Authors are encouraged to report this issue directly to the CMC Editorial Office (cmc@techscience.com) in a timely manner once it is occurred.

Thank you very much for your contributions to CMC-Computers, Materials & Continua.

Author response:

Dear Editor,

Thank you very much for your time in evaluating this manuscript and the opportunity for revising and resubmitting our paper after revision. Please see the following as our responses to the comments raised by the reviewers. I sincerely hope they are satisfactory.

Reviewer#1, Comment #1

You have done this revision well.

Please make sure your paper has necessary language proof-reading.

Author response:

We thank you for your effort in evaluating this work. We have submitted to Enago as professional copy editing services for this manuscript and achieved Certificate of Editing (COE).

enago www.enago.com | voxtab www.voxtab.com | ulatus www.ulatus.com

CERTIFICATE OF EDITING

This is to certify that the paper titled **Digital Forensics for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management** commissioned to us by **Imam Yuadi.** has been edited for English language and spelling by Enago, an editing brand of Crimson Interactive Inc.

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Reviewer#2, Comment #1

* References

- Paper title: only the initial letter of the first word is uppercase.

- Journal title: should be in italic, and the initial letter of each notional word should be in uppercase.

Author response:

We thank you for your comments and suggestion. We have revised the references [3, 4, 22, 28, 32, 35, 39 , 45, and 50] such as your suggestion.

Reviewer#2, Comment #2

* English:

English should be revised and corrected further. It is still inadequate for publishing

Most of the errors now have to do with missing articles, conjunctions, prepositions, pronouns, verbs …

And mostly:

Too many words repetitions:

Repetition and redundancy can cause problems at the level of either the entire paper or individual sentences

- Use a variety of different transition words.

Tips for avoiding the most common forms of repetition:

• Use a variety of different transition words

Author response:

We thank you for your comments and suggestion.

Reviewer#2, Comment #3

Some sentences are too long:

- Break up your sentences

Tips for avoiding the most common forms of repetition:

- Vary the structure and length of your sentences.

Author response:

We thank you for your comments and suggestion. We revised for breaking up our sentences from one sentence into two sentences.

Section 1 Paragraph 1

This process is important for ensuring that the skulls have a code as an identity of the collection and for ease of their identification. Equally important is for the proper documentation, development, maintenance, and enhancement of existing collections and for their availability to users who want to use them according to the classification standard in the curation field [2].

Section 1 Paragraph 2

However, the utilize of ink streaked on skulls for the purpose of giving a number and letter code can damage the authenticity of the skull as research and study material. Hence, the management of skull collections necessitates a certain approach in order to maintain the authenticity of the collection and not damage the bones and skulls from the chemicals attached.

Section 2 Paragraph 1

For the purpose of facial recognition, automatic face processing [19,20] is considered to be a reliable method and realistic approach [21]. It benefits from using deep neural network [22], dictionary learning [23], and automatic partial learning [24].

Reviewer#2, Comment #4

Sentence Repetition:

- Avoid repetition at the sentence level

- Avoid sentences that restate the main point of the previous sentence.

- Don’t restate points you’ve already made.

- Don't use the same pronoun to reference more than one antecedent (e.g. “They asked whether they were ready for them”)

Tips for avoiding the most common forms of repetition:

• Use a variety of different transition words

• Vary the structure and length of your sentences

• Don’t use the same pronoun to reference more than one antecedent (e.g. “They asked whether they were ready for them”)

• Avoid redundancies (e.g “In the year 2019” instead of “in 2019”)

• Don’t state the obvious (e.g. “The conclusion chapter contains the paper’s conclusions”).

Author response:

We thank you for your comments and suggestion.

CMC-15417-revised_paper_with_track_changes_blue_highlighting

Type: xxx

Digital Forensics for Automatic Recognition of Human Skulls in Physical Anthropology Collection Management

Imam Yuadi[1,*], Myrtati D. Artaria[2], Sakina[3], and A. Taufiq Asyhari[4]

[1]Department of Information and Library Science, Airlangga University, Surabaya, 60286, Indonesia

[2]Department of Anthropology, Airlangga University, Surabaya, 60286, Indonesia

[3]Department of Anatomy and Histology, Airlangga University, Surabaya, 60286, Indonesia

[3]School of Computing and Digital Technology, Birmingham City University, Birmingham, B4 7XG, United Kingdom

[*]Corresponding Author: Imam Yuadi. Email: imam.yuadi@fisip.unair.ac.id

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Abstract: The human skull has a size, shape, and physical characteristics that are distinctive among individual humans. In physical anthropology, correct management of skull collections is crucial to storing and maintaining the collections cost-effectively. For example, incorrect labeling of skulls or attaching printed labels to skulls can affect the authenticity of collections. Given the multiple issues associated with manual identification of skulls, in the present study, we propose an automatic human skull classification approach that uses a support vector machine and different feature extraction methods such as Gray-level Co-occurrence Matrix features, Gabor features, Fractal features, Discrete Wavelet Transform, and features combination. We found that each facial bone underlying the respective facial structures had unique characteristics essential to the physical structure of faces that could be exploited for identification. Given this finding, we then developed an automatic recognition to classify human skulls as a strategy of consistent identification compares to the traditional classification approaches. By using our proposed approach, we are able to achieve 92.3% - 99.5% accuracy for classifying human skulls with mandibles and those without a mandible with 91.4%–99.9% accuracy. Our study represents a step forward in constructing an effective automatic human skull identification system via a classification process that achieves a satisfactory performance for a limited dataset of skull images.

Keywords: Discrete wavelet transform; Gabor; gray-level co-occurrence matrix; human skulls; physical anthropology; support vector machine

1 Introduction

1.1 Background and Motivation

Participants in the field of digital forensics commonly deal with issues closely related to the law that involve a series of activities including collecting, examining, identifying, and analyzing the digital artifacts required to accumulate evidence related to document misconduct [1]. Several research challenges share the digital forensics attributes found in crime investigation in the subject area of physical anthropology. One prevalent example is the management of skull collections in museums to preserve all stored collections and the development of knowledge as well as for the benefit of research and future education. A key component in skull collection management is the skull cataloging and retrieval system. Within this system, the investigation process can be utilized to identify skulls with lost labels to recover and match unidentified skulls to their existing skull code. This process includes various activities and actions, including labeling the collection in the form of a call number attached to the skull. This process is important for ensuring that the skulls have a code as an identity of the collection and for ease of their identification, as well as for the proper documentation, development, maintenance, and enhancement of existing collections and for their availability to users who want to use them according to the classification standard in the curation field [2].

However, the utilize of ink streaked on skulls for the purpose of giving a number and letter code can damage the authenticity of the skull as research and study material; therefore, the management of skull collections necessitates a certain approach in order to maintain the authenticity of the collection and not damage the bones and skulls from the chemicals attached. An alternative to marking skulls is attaching stickers that identify the call number. However, this also has drawbacks because the sticker can become loose, fall off the skull, and become mixed with other similar skulls.

Consequently, there is a challenge in increasing the number of new skeleton collections because of difficulties in the storage and collection of these bones. These skulls can include those that have been separated from the mandible and many that did not have a mandible when first discovered. Likewise, labeling errors are a major problem when human skulls and other skeletal collections in an anthropology forensics laboratory have been "inked out." Besides the loss of labels attached to new bone collections, the mixing of old bone collections with the new bones and high usage factors are each a challenge that must be overcome in the management of skeleton collections.

The use of digital cameras by anthropologists and other researchers to determine the human bones and associated skeleton of a dead person is currently limited to manual investigation and comparison [3-4].–Although some previous studies have applied automatic means such as machine learning to identify human skulls, most of the samples were obtained from computerized tomography (CT) scans of living participants [5-7]. However, these samples have limited relevance to the analysis of dead human skulls in many cases of physical anthropology forensics.

1.2 Contributions of This Work

In the present study, we therefore investigate a digital forensics approach to physical anthropological investigation of dead human skulls on the basis of their specific characteristics. Our main contributions are as follows. Firstly, the significance of this work lies in the utilization of machine learning and data analytics knowledge to a new domain of physical anthropology collection management to address the associated unique challenges. Secondly, given the aforementioned problems introduced by manual labeling techniques, the present work aimed to evaluate relevant contrasting features of human skulls based on different characteristics as well as to build the skull-based identities from various positions using an automatic classification. Thirdly, our work proposes automatic recognition of the skull beneath a human face that would allow curators to identify identity features according to the characteristics of a skeleton. This technique would potentially assist in the management of museum collections or laboratory storage of skulls, which could be identified without being manually marked or labeled, which in turn would maintain the authenticity of the skeleton.

The inspiration for the present study comes from the science of face recognition in which analyses of the characteristics of human physical characteristics of the face are performed via images acquired with a digital camera [8]. Various means and properties can be used to recognize the structure of the mandible, mouth, nose, forehead, and the overall features that make up human skulls. Based on the availability of these properties, face recognition can be conducted by comparing different faces captured in images and classifying them by implementation of support vector machine (SVM) as a machine-learning tool. Several studies [9-12] applied SVM to identify human faces using a different approach. It can achieve face prediction accuracy rates >95%. These studies applied different feature processing methods to acquire relevant statistical values prior to classification. Specifically, Benitez-Garcia et al. [12] and Hu [13] applied discrete wavelet transform (DWT) for feature extraction to identify human face. Eleyan [14] also uses wavelet transform and Dabbaghchian implemented discrete cosine transform (DCT) as well for human face analysis [15]. To improve the accuracy of prediction, Krisshna et. al using the transform domain feature extraction combined with feature selection [16]. In contrast, Gautam et al. [17] proposed image decomposition using Haar wavelet transforms through a classification approach combining quantization transform and a split-up window on the facial images. By using feature extraction in grayscale morphology, faces were classified with backpropagation neural networks to be distinguished from other faces. A combination feature extraction of Gaussian and Gabor features has also been applied to enhance the verification rate of face recognition [18].

As we found in the present study, effective combination of different feature filters is a step forward toward using machine learning for investigations in physical anthropology and its sub - areas. A distinct characteristic in this physical anthropology field appears from the analysis of dead human skull data, which is rarely found in the previous studies of automatic face recognition. This work, therefore, offers a new perspective of machine learning application to this new anthropology domain where associated challenges exist, i.e., limited physical collection of the dead human skulls, variation in completeness of the skull construction and deteriorating skull conditions over time. All these conditions pose disturbances to train appropriate machine learning techniques and obtaining the right features is the key to achieve the learning objective.

The remaining sections of this manuscript are systematically arranged as follows. Section 2 contains related works. Section 3 discusses the skull structure that forms the initial information for skull classification. Section 4 presents our main research approach and contribution to developing a machine learning-based automatic classification platform for classifying human skulls in physical anthropology. Section 5 reports our experimental results, which validate our research approach in the previous section. Finally, the main results of this research and the direction of future work, we summarize in Section 6.

2 Related Works

There is a growing necessity for an image recognition-based image classification system that can perform automatic face recognition tasks [19-24] for multiple everyday requirements. Studies on facial recognition and facial perception have been conducted extensively (see [19-30] for some examples). For the purpose of facial recognition, automatic face processing [19,20] is considered to be a reliable method and realistic approach [21]; it benefits from using deep neural network [22], dictionary learning [23], and automatic partial learning [24]. These tools can be utilized to create a practical face dataset acquired from inexpensive digital cameras or video recorders with maximum capabilities. It is important to note that several studies have also addressed human recognition on the basis of a variety of body images taken by cameras.

Elmahmudi and Hasan studied face recognition through facial rotation of different face components, i.e., the cheeks, mouth, eyes, and nose, and by exploiting a convolutional neural network (CNN) and feature extraction prior to SVM classification. Duan et al. [24] investigated partial face recognition using a combination of robust points set to match Gabor ternary patterns to local key points. Several studies considered using CNNs to extract complementary facial features and derive face representations from layers in the deep neural network, which could achieve highly accurate results.

Furthermore, Chen et al. [25] applied similarity learning by using a polynomial feature map, which was recently proposed to illustrate compatibility in each sub-region of the human face, and injecting all mapping features into an integrated framework. This technique was also used by Wu et al. [26], who combined deep CNNs and gait-based human identification; they examined various scenarios, namely, cross-walking conditions and cross-view. Koo et al. [27] also studied human recognition via a multimodal method by analyzing the face and body [28-29] on the basis of a deep CNN [30].

Previous anthropology literature [31] provided complete information for facial identification by investigating skull objects at different positions. In the area of forensic anthropology, experts use bones and skulls as information to identify missing people through facial reconstruction and determine sex [3]. Identification of craniofacial superimposition can provide forensic evidence about sex and specific identity when humans live. Additionally, the shape of the tooth structure also provides information about the food consumed. Craniofacial superimposition is a skeleton residue, which can give forensic artefacts prior to identification. Hence, a skull overlay process is applied by investigation experts to examine ante-mortem digital figures that are popular in skull morphology analysis [4].

More specific to the forensic anthropology approach is the so-called computational forensics method [32]. In this area of research, Bewes et al. [5] adapted neural networks for sex determination on the basis of human skulls using data from hospital CT scans. Automatic classification to determine gender has also been conducted by Walker [6], who investigated and visually assessed modern American skulls through five skull traits. He used a discriminant function analysis to compute sex determination based on pelvic morphology. His technique can achieve 90% accuracy rate prediction for the skulls. Meanwhile, another study on the skulls of white European Americans was conducted by Williams and Rogers [7], who accurately identified more than 80% of the assumed identities. Another approach by Angelis [33] was developed to predict soft face thickness for face classification.

As observed from a vast majority of the aforementioned works, automatic face recognition has been largely focused on the analyses of data taken from living human; be it in the form of digital camera captures or in the form of CT images. While physical characteristics for facial identification and computational forensics for gender classification have been investigated in the anthropology literature, the availability of automated digital tools that are robust in facial identification with and without missing components appears to be lacking. This work is a step forward in developing such an automatic tool by incorporating machine learning and data knowledge towards understanding robust features.

3 Skull Structures

In principle, the facial skeleton or viscerocranium comprises the anterior and lower and skull bones, namely facial tissue and other structures that construct the human face. It is formed from various kinds of bones which derived from branchial arches that are interconnected among the bones of the eye, sinuses, nose, and oral cavity are unity in calvarias bones [34]. The viscerocranium encompasses several bones illustrated in Fig. 1 and organized as follows.

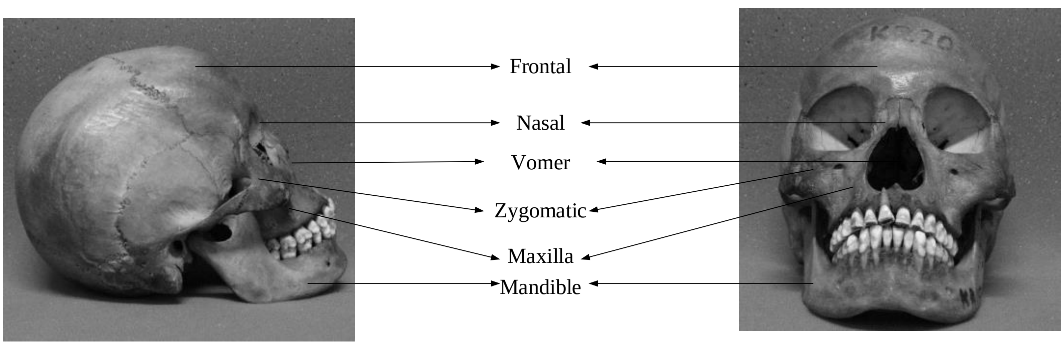


Figure 1: The structures of a human skull

1) *Frontal*—This bone consists of squamous which tends to be vertical and the orbital bones are oriented horizontally. The squamous forms part of the human forehead. Meanwhile, the orbital part is the part of the bone that supports the eye and the nose respectively.
2) *Nasal*—The paired nasal bones have different sizes and shapes but tend to be small ovals; these bones have a function to unite the cartilage which is located in the nasofrontal and upper part of lateral

cartilages to form the human nose. It consists of two neurocranium and two viscerocranium.

3) *Vomer*—The vomer bone is a single facial bone and an unpaired midline that attaches to an inferior part of the sphenoid bone. It articulates with ethmoid, namely two maxillary bones and two palatine bones forming the nasal septum.
4) *Zygomatic*—The zygomatic bone is a cheekbone position within the lateral side and forms the cheeks of a human. This bone has three surfaces namely orbital, temporal, and lateral. It articulates directly with the other four bones, namely the temporal bone, the sphenoid, the frontal bone, and the maxilla.
5) *Maxilla*—This is often referred to as the upper jaw bone and is a paired bone that has four processes, namely zygomatic, alveolar, frontal, and palatine. This bone supports the upper jaw teeth but does not move such as the lower jaw or mandible.
6) *Mandible*— The mandible is the lower jaw bone or movable cranial bone which is the largest and strongest facial bone of the face. It can open and close a human's mouth. The mandible body has two basic bones, namely the alveolar part and the mandible base, which is located in the anterior part of the lower jaw bone. Furthermore, it has two surfaces and two borders [35].

4 Research Approach

In the following subsections, we describe the systematic design steps taken to develop an automatic intelligent human skull recognition system using data collection and processing, feature extraction filters, and skull classification to obtain maximum prediction accuracy.

4.1 Tools and Software Platform

To conduct a forensics test on human skulls, we used hardware and software platform requirements in accordance with the objectives of this study. First, the DSC-HX300 Digital camera is a tool for taking skull images equipped with the high-resolution Carl Zeiss lenses. Second, we applied the Matlab software version R2013a to extract image data into numeric form. Finally, we implemented the SVM classifier with Eclips SDK based on Java language to classify the skulls. To run the aforementioned software, we used a personal computer with specifications: an Intel Core i5 Processor equipped with 8GB of RAM using the Windows XP operating system.

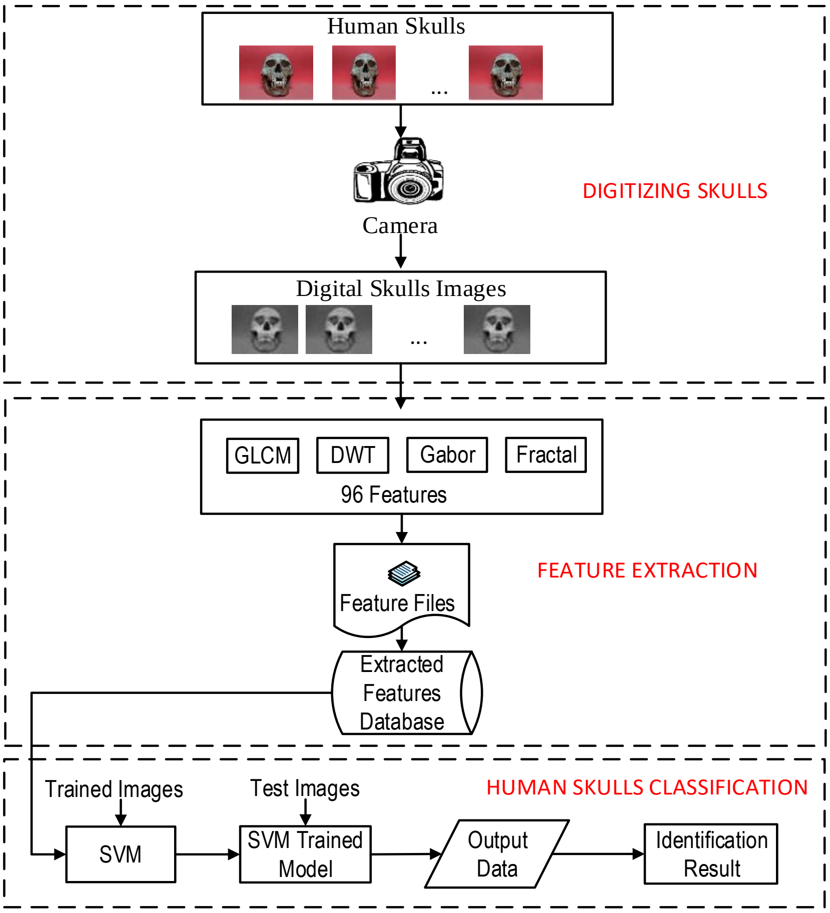


Figure 2: Framework used for digital forensics in investigating characteristics of human skulls.

4.2 Framework

Fig. 2 depicts a framework used for digital forensics in the context of investigating characteristics of human skulls in this work. This diagram captures step-by-step investigation procedures, which begins with digitalization of skull data and ends with skull identification. This detailed process is explained as follows.

1) Digitizing human skulls: In the first step, the skulls were digitized by taking photos of each skull from various angles using a digital camera. The angles are face or front, left, right, bottom, and top areas. The results were then documented and saved as digital image files. Fig. 4 illustrates the region of interest (ROI) of an image sample which shows the skull area corresponding to a set of pixels, where (i, j) denotes a spatial location index within the picture.

2) Feature extraction: This step is conducted to acquire certain values from the skull images by feature filtering or extraction based on the characteristic of the pixel and the other criteria. We applied different feature filters to get a comparison of the accuracy rate among the implemented filters. This stage is the major image processing activity prior to the next step of segmentation and classification. To determine relevant features and extract their corresponding values from images, we considered four different feature-filtering techniques. We conducted a texture analysis approach using this feature filter before human skulls are classified. There are four feature filter separately applied to acquire the accuracy rate. For this study, we used 22 features-level co-occurrence matrix (GLCM), 12 features of Discrete Wavelet Transform (DWT), 48 features of Gabor, and 24 fractal features or segmentation-based fractal texture analysis (SFTA). The total features are 106 features when combined from entirely feature filters. The filters are applied to analyze 24 image skulls with different rotation angles from 1 ° to 360 ° where each image is extracted with these filters to acquire a different statistical decomposition. Therefore, each skull image produces a minimum of 360 images to be extracted by deploying different filters before classification.

3) Classification: The support vector machine (SVM) is a widely applied method studied by Awad and Khanna [36] for data classification and regression. It can maximize the distance between several data classes, even when applied to a high dimension of input space. It also has the ability to process and group images based on the pattern is SVM's strength, especially the curse of dimensionality. Furthermore, SVM has the ability to solve the problem of limited data training and is able to minimize the risk of structure with the ability to work on non-linear problems by adding a high-dimensional kernel concept [37,38]. Modestly, SVM works by finding the best hyperplanes to classify different space classes in the input space. By finding a hyperplane that separates groups or classes through margins and maximum points, the classification could be conducted. Therefore, it can run on non-linear kernel data with the kernel non-linear kernel functions through the mapping of the product point from low dimensions to higher dimensions. In the present study, radial basis function (RBF)-based kernels were chosen to build a non-linear classifier to identify 24 different types of skull. More specifically, to build this SVM-based classifier, we applied an RBF-based kernel function used in [39], i.e.,

$$K_{RBF}(x_i, x_j) = \exp(-\gamma \|x_i - x_j\|^2) \quad (1)$$

Herein the variables $\gamma > 0$ and $\|.\|$ denote a kernel spreading coefficient and the Euclidean norm applied to the difference between two data points x_i and x_j , respectively. The value of γ was optimized using a coarse grid search via transformation of original data to feature space.

4.3 Feature Extraction

Feature extraction involves transformation of data: derivative values from the original data are built into variable data with statistical values that can be further processed. Here, we used the following techniques for feature extraction.

1) GLCM is a popular filter for analyzing textures. It captures information on gray-valued spatial distribution in an image as well as its corresponding frequency at given specified angles and distances. Extracting features using GLCM through the estimated probability density function of a pixel is formed by a co-occurrence matrix with its pixel pairs where features can be statistically and numerically quantified [40,41]. Four angular directions can be considered during the matrix generation for feature extraction. Specifically, statistical characteristics are calculated on 0°, 45°, 90°, and 135° directions.

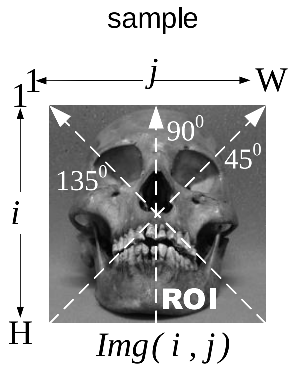


Figure 3: The texture orientation estimation in the skull image. The pixel of GLCM (n, m) from four different regions of interest (ROI) where the spatial location of the skull image is *i* and *j*. At the point, the pixel separation (*W* and *H*) which are applied *W* = 0 and *H* = 1 to construct the number of gray level pixels' n and m**.**

Fig. 3 shows the direction (horizontal and vertical orientation) as a spatial representation from the different reference pixels. Suppose that reference pixel *i* is defined as a 45° orientation that locates an adjacent pixel. Calculating the direction of the pixel is performed at pixel *j* next to pixel *i* as demonstrated by Tsai et al. [42]. Following this work, Fig. 4 illustrates the ROI of human skulls showing pixels generated by GLCM in gray color, as captured in Eq. (2):

$$\boldsymbol{R} = \sum_{(\boldsymbol{i},\boldsymbol{j})\in \boldsymbol{ROI}} \mathbf{1}.$$
(2)

In other words, pixels are labeled as "1" if they belong to the ROI and "0" otherwise. From Eq. (2), we are then able to acquire the predictable values from the normalized GLCM [42]:

$$GLCM\ (i,j) = \frac{1}{\sum_{(i,j)} Img(i,j)} Img(i,j). \quad (3)$$

Herein (*i*, *j*) denotes the index of the pixel in the image and *Img*(*i*, *j*) is the probability value of the pixel index (*i*, *j*). The GLCM method can generate 22 texture features as explained in detail by Tsai et al..

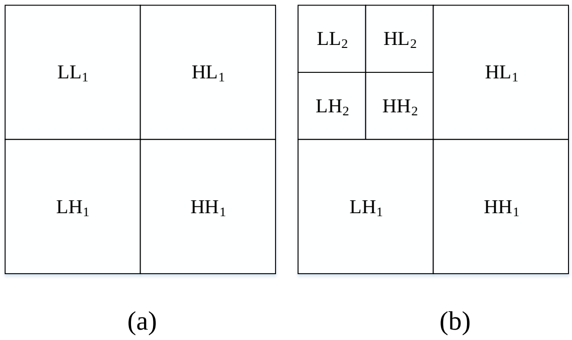


Figure 4: Discrete wavelet transform (DWT) image decomposition for (a) one level and (b) two levels.

2) Wavelet features. A digital image is made up of many pixels that can be represented in a 2-D matrix. Conversely, outside of the spatial domain, the frequency domain can represent an image using a spectrum method called the DWT. In several studies (e.g., [43,44]), the feature sets focus on 2-D scale wavelets because of the underlying functions. The feature filter direction follows subsampling with two factors and each sub-band is equivalent to the output filters, which contain some samples as compared with the main 2-D matrix. DWT coefficients are filtered processing outputs. This filter set of DWT coefficients, as shown in Fig. 4, contains 12 statistical features that include kurtosis (HH, LH, HL, and LL sub-bands), standard deviation, and skewness.

3) Gabor features. Gabor filters are shaped through a process of dilation and rotation in a single kernel with several parameters. The corresponding filter function is used as a kernel to form a dictionary filter to analyze texture images. In the spatial domain, the 2-D Gabor filter has several benefits in a spatial domain such as scale, invariance for rotation, illumination, and translation involving the Gaussian kernel function [45] that is modulated by complex sinusoidal waves [46-47]. Inspired by these works, to extract human skull images, we use the function in Eq. (4):

$$GG(x, y, \theta, f) = \exp\left(\left[-\frac{1}{2}\left\{\left(\frac{x'}{Sx}\right)^2 + \left(\frac{y'}{Sy}\right)^2\right\}\right]\right)\cos(2\pi f x'). \quad (4)$$

Here we have the parameter x' defined by $x\cos(\theta) + y\sin(\theta)$ and y' given by $y\cos(\theta) - x\sin(\theta)$. On the other hand, we have S_x and S_y to denote the variances in in x and y axes respectively. Finally, the parameter f denotes the frequency of the sinusoidal function, and θ represents the orientation of the Gabor filter. Subsequently, it considered the following numerical values as part of Gabor feature extraction: $S_y = 4$; $S_x = 2$; $f = 2, 4, 8$, and 16; and $\vartheta = 0, \pi/2, \pi/4$, and $3\pi/4$. We then extracted and acquired all 48 Gabor features from each image.

4) Fractal features are considered in the evaluation of images with content-similar textures. Features are constructed from fractal dimensions of transformed images obtained from the boundary of segmented image structures and grayscale images that describe objects. Along with the capability to compute the fractal dimension of any surface roughness, fractal features can evaluate the gray image and compare a variety of textures. Fractal dimensions can be realized as a measure of irregularity or heterogeneity of the arrangement of an area on a different scale. If an object has self-similarity properties, then the entire set of minimized subsets will have the same properties. In the present work, the boundaries of the feature vector can be used to measure fractals. Following this work, the measurement is represented by $\Delta(x, y)$, which is given in Eq. (5):

$$\Delta(x, y) = \begin{cases} 1, & if\ \exists(x', y') \in N_4[(x, y)] \ : \\ & I_b(x', y') = 0 \wedge I_b(x', y') = 1, \\ 0, & otherwise. \end{cases} \quad (5)$$

In this equation, $N_4[(x, y)]$ denotes a grayscale skull image that has 4 connected to (x, y) in a group of pixels. When the pixel $\Delta(x, y)$ has a value of 1 and the pixel position value (x, y) can be transformed in the binary image I_b or the value is 1 with a minimum of one pixel in the neighborhood having a value of 0. Otherwise, $\Delta(x, y)$ is assigned to 0. For binary decomposition, previous studies [48,49] applied a thresholding mechanism to the input image. In the present study, we applied 4-connected pixel on the threshold segmentation to (x, y); we were able to extract 24 features.

4.4 Data Samples

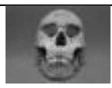
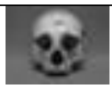
In the present study, the identification of human skulls was categorized based on their existing mandible. The samples were distinguished to validate and compare the unique characteristics of various human skulls, not only skulls with mandibles but also those without a mandible, as shown in Fig. 5. To obtain fair research results, we selected each of the 24 samples of the same population image both for skulls with mandibles and skulls without mandibles. We then digitized them using a Sony Cyber-shot DSC-HX300 digital camera.

We experimented with seven different angles for the images of skulls with and without mandibles: front, top and back angles, as well as 45° right-angle, 45° left angle, 90° right-angle, and 90° left-angle rotations. We then rotated the image step by step over 360° where every one degree of rotation produces one sample image to be stored as input samples on machine learning. For example, the front angle was rotated over 360°. Thus, we analyzed 360 data samples. We converted all images to grayscale in jpeg (jpg) format, set a pixel size of 53 × 40 for each image, and set the file size to 4 kb. Tab. 1 details the 360 processed sample images for each skull image, which were obtained using rotation: the total number of images used in this experiment was 8640. Thus, we classified 24 images of a human skull as classes. Each sample was rotated 1° continuously to obtain 360 different samples up to 360°. Each sample was rotated 1° continuously to obtain 360 different samples up to 360°. Therefore, each sample produced 360 × 24 images, which resulted in 8640 images being processed for each angle. The result of a given experiment is the average taken from the 10 rounds of the given experiment. Remark that for each round of experiment, a set of 300 instances are uniformly sampled across the total 8640 image instances, which come from number of human skull samples/classes (24) multiplied by the number of rotations (360).

Figure 5: Skulls with a mandible (top) and without a mandible (bottom).

This set is then proportionally partitioned into training and test datasets with a ratio of 2:1. This partition will ensure no mixing between training and test. The 10 image sets of size 300 each corresponding to 10 different rounds of experiment are mutually exclusive, meaning that an image used for one particular experiment will not be used for the other experiments.

Table 1: Characteristics of human skulls data

Category	Sample	Pixels	Size	Total data
Skull with mandible		53 × 40	4.00 kb	8640
Skull without mandible		53 × 40	4.00 kb	8640

4.5 Research Limitation

The limitation of this study can be identified from the use of the same digital camera brand to ensure that the resolution is the same for capturing skull images. We are also constrained with the seven different angles to perform comparison between skulls with mandible and skulls without mandible. Due to the difficulty of finding human skulls as the research object, this study focuses on the classification of 24 skulls, which are all in incomplete conditions, especially for the teeth attached to the skull.

5 Experiment Results

As previously described, we considered two different data types in the form of digital images: skulls with mandibles and incomplete skulls without mandibles, which were obtained from the Physical Anthropology Laboratory at Airlangga University. We made these data to be accessible from: http://fisip.unair.ac.id/researchdata/Skulls/). To clearly understand the factors influencing the experimental results, we first applied each feature extraction filter separately. This process was followed by combining all the feature extraction filters. The following sections discuss this process in more detail, specifically focusing on the classification accuracy.

5.1 Experiment I: Identification of Skulls with Mandibles

In Experiment I, we considered images of human skulls with mandibles and examined them from different angles. For comparison purposes, we conducted experiments by processing data from different skulls positioned as shown in Fig. 6. Seven different angles were used to capture images of human skulls as mentioned in Section IV-D. However, prior to classification, the feature extraction techniques described in Section IV were applied to the images, and Matlab was used to acquire the numerical values of the generated features. Afterward, we exported the numerical values on the basis of a filter set into a MySQL database for future referencing. Subsequently, we performed image-driven skull classification using SVM implemented in a Java programming environment to compute the accuracy rate of the classification task on the basis of a given set of features. We considered all individual treatments of each feature extraction filter in Section IV and the features combined from all the filters. Note that the accuracy rates of predicting the skulls from different angles are tabulated in Tab. 2. for comparison.

The detailed steps in this experiment were as follows:

(1) We used 24 sets of images that were extracted using a variety of extraction filters. Each resulting set of images contained 360 transformed images obtained by rotating the original image by one-degree rotation per step. From all the available images, we then selected 200 skull images as training datasets and we applied 100 skull images as testing data. Our four extraction filtering techniques from Section IV were then applied for feature extraction.

(2) After Step (1), we ran SVM to predict human skulls with mandibles using the four filtering techniques individually and a combination of all four filters.

(3) We then conducted a series of image testing steps on the basis of the appropriate model constructed in Step (2) for human skulls with mandibles.

(4) Finally, we repeated Steps (1) to (3) nine times more (ten replicates) and obtained the average performance from the dataset of skulls with mandibles.

The classifications of skulls with mandibles tabulated in Tab. 2. have different accuracies according to the seven angles of interest. Evidently, each filter also produced a different accuracy level, even though the within-filter results were relatively numerically stable. The Gabor feature extraction was stable above 90%, which makes it the superior feature filter among the four considered techniques. In contrast, the DWT filter gave an accuracy rate as low as 89.73%. Conversely, the GLCM, Gabor, and fractal filters consistently achieve >98% classification accuracy. With prediction accuracies mostly >90%, all four filters are promising tools for assisting SVM in automatically classifying human skulls for physical anthropology applications.

(a) (b) (c) (d) (e) (f) (g)

Figure 6: Various angles used for depicting images: (a) front angle, (b) 45° right angle rotation, (c) −45° left angle rotation, (d) 90° right angle rotation, (e) −90° left angle rotation, (f) top angle, and (g) back angle.

Table 2: Accuracy prediction (%) for human skulls with mandibles

Filter Name	Front	−45° left	45° right	-90^0 left	90° right	Back	Top
GLC	98.07	99.90	99.75	99.76	99.81	99.74	99.99
DW	92.37	94.05	89.73	94.01	93.77	94.97	97.05
Gab	99.24	99.55	99.21	99.43	99.45	99.44	99.69
SFT	99.33	99.21	99.00	98.98	98.57	98.68	99.51
All	99.52	99.57	99.53	99.57	99.39	99.46	99.80

5.2 Experiment II: Identification of Skulls without Mandibles

To evaluate the robustness of our classification system, we conducted identifications of skulls without mandibles. The method was exactly that followed for the identification of skulls with mandibles. Likewise, 8,640 images also comprised the dataset for each angle position.

Tab. 3 presents the performance accuracy of the five filters for human skulls without mandibles (Note that we selected 24 out of 99 available samples in this table). The classification results using SVM varied according to the different feature extraction filters. Overall, the GLCM filter offered superior prediction capabilities, achieving more than 99% accuracy for all the angular positions of the skulls. DWT again had the lowest accuracy of the filters. Almost all the filters had prediction accuracies >90%, except DWT at −45° left (88.36%). When combining the features from all filters, the prediction accuracy was 99.61%.

In an automatic human skull classification, implementing feature extraction and combining different feature filters plays a significant role in accumulating relevant features for classification of the images dataset. Obviously, each filter can produce several features. By using four different filters and combining all features generated by these filters, classification system with diverse results can be produced. For example, in the present study, using GLCM, which consists of 22 features, resulted in a classification accuracy rate of 99.86%–99.95%, depending on the angular position of the skull. Conversely, DWT feature extraction had a much lower accuracy rate of 88.36%–96.24%.

Table 3: Accuracy prediction (%) for human skulls without mandibles

Filter Name	Front	−45° left	45° right	-90^0 left	90° right	Back	Top
GLC	99.95	99.92	99.88	99.87	99.86	99.87	99.95
DW	91.45	88.36	92.18	90.58	93.43	95.18	96.24
Gab	99.29	99.19	99.39	99.27	99.34	99.65	99.63
SFT	98.97	99.00	98.46	98.82	98.69	99.42	99.48
All	99.61	99.56	99.56	99.32	99.46	99.50	99.72

5.3 Experiment III: Different Resolutions for Skull Classification

To compare and validate the results of the first experiments, we also used different electronic imaging devices in a subsequent experiment. In the previous experiments, we used a camera with a high resolution; however, in Experiment III, we used a mobile camera (NOKIA 3.1 plus) with a lower resolution. We used the same experimental approach but captured the skull front-face images with the different lens size settings for camera resolution: 2, 4, and 9 MP.

Table 4: Accuracy prediction (%) for different resolutions

Filter Name	2 MP	4 MP	9 MP
GLC	91.41	93.17	97.83
DW	67.38	67.89	70.07
Gab	88.48	91.50	93.55
SFT	79.32	80.20	90.67
All	83.75	86.98	94.62

Tab. 4 shows the accuracy prediction percentages when identifying human skulls using the three different megapixel camera resolutions. Clearly, with higher resolutions, there was greater accuracy in the predictions. For example, a 2 MP camera resolution produced an accuracy prediction for GLCM of 91.41%, which was lower than that for a 4 MP resolution, 93.17%, and a 9 MP resolution, 97.83%.

5.4 Discussion

Our experiment results indicate that the classification of the skull with mandibles is as accurate as of the skull without mandibles. However, the required calculation time for processing images of skulls with mandibles was shorter than that for skulls without mandibles.

This study extends the analysis and framework for the identification of human faces reported in previous studies [9-15] with novel scenarios captured in the context of human skulls. Results from previous studies are summarized in Tab. 5 as an indicator of identification accuracy. The majority of these approaches achieve an average accuracy above 90% in the overall testing data. The lowest accuracy is observed in the method used by Dabbaghchian et al. [15] (86.81%). Other studies [9-14] have much better accuracies and an average accuracy percentage of >94%. The most accurate approach came from research with CNNs [11], in which the accuracy percentage was 98.43%. Other approaches, such as principal component analysis and discrimination power analysis [13], also have a relatively high percentage of accuracy. Nevertheless, our method of analyzing the human skulls rather than human faces of living persons produced accuracies that exceed these methods. Using the framework in Fig. 2, which shows a new approach with many feature filters combined, we produced higher classification accuracy when identifying skulls. Thus, we can conclude that our novel approach could be a promising application in digital forensics of human skull identification.

Table 5: Different result approach for face recognition

Research	Research Object	Approach	Accuracy Rate
[9]	Live Human Face	Principal component analysis (PCA), Particle swarm optimization (PSO)-SVM (PSO-SVM)	98.00%
[10]	Live Human Face	PCA, Euclidean, Gaussian Mixture Model (GMM)	97.04%
[11]	Live Human Face	CNNs	98.43%
[12]	Live Human Face	PCA, sub-block processing	97.60%
[13]	Live Human Face	PCA, dual-tree complex wavelet transform (DT-CWT) and the single-	94.67%

		tree complex wavelet transform (ST-CWT)	
[50]	Live Human Skull	PCA	95.70%
Our Work	**Dead Human Skull**	SVM	99.50%

Unlike human face research [9-13], one of the great challenges in the present study was the acquisition of human skull data. This is because the skull is an inanimate object that must be moved to obtain data from various angles. We performed this movement by manually turning the skull to appropriate angles to obtain images from various positions. This is highly challenging, especially when the skull is in an incomplete condition.

A variation of sizes in training data can impact the accuracy of the classification task. It is of interest to investigate how different training sizes can shape the performance of SVM classification. The results of prediction accuracy rates for skulls with and without mandibles based on the number of training and testing data affects the percentage of the prediction accuracy. For example, with the GLCM filter, when using only one training data for predicting skulls with mandibles, we obtained an accuracy rate of 18.33%; however, when using 100 training data, the accuracy rate was 97.03%. Thus, the more amount of training data applied will yield a high level of accuracy. Conversely, the less training and testing data used will affect the lack of accuracy in predicting skulls with and without mandible

Skulls generally consist of one dominant texture and color. They have different shapes and sizes if they are from the same race. Although they are buried in different soil structures (for example clay and calcareous soils); they will have different bone colors even in the same race.

In this forensic study, we applied a digital camera to digitize the skulls. Of course, the implementation of different digitizing tools will affect the level of accuracy especially the difference in pixel size. Therefore, in further research, we can use advanced digital technology capabilities such as PMCT angiography, postmortem computed tomography (PMCT), and X-rays.

Because of the limitations and difficulties in obtaining sample data in physical anthropology, the present study focused on only 24 human skulls with mandibles and 24 skulls without mandibles. However, we also conducted experiments on other skulls without mandibles, totaling 99 skulls, even though the conditions were incomplete in some bone structures when they were discovered. Therefore, we only focused on the classification of skull faces. Our results were similar to those from Experiments I and II, although the level of accuracy was slightly higher than in the previous experiments.

6 Conclusion

Here, we developed an automatic computerized digital forensics approach for human skull identification using feature extraction in tandem with SVM for classification. We applied a digital forensics framework to classify human skulls with and without mandibles. For feature extraction, we tested four different feature extraction filters that resulted in different classification accuracies. GCLM achieved the maximum accuracy with features generated from Gabor and fractal features (>99% accuracy). In contrast, DWT features had identification prediction accuracies <95%. We also note that combining the four feature extraction techniques produced an accuracy rate >99% for both skulls with and without mandibles. Thus, we conclude that every human skull has unique features that can be used to distinguish its identity in forensics applications, especially in physical anthropology collection management.

We can identify several future directions for research related to skulls identification. For future work, it will be necessary to optimize the combined feature extraction and classification method and to explore other feature extraction techniques and classification methods for performance comparisons. The use of more skulls data using the CNN method can be the main focus for future research. Furthermore, determining the age and gender of the skulls will greatly assist researchers in identifying humans who have disappeared due to natural disasters and criminal events.

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Article

Digital Forensics for Skulls Classification in Physical Anthropology Collection Management

Imam Yuadi[1,*], Myrtati D. Artaria[2], Sakina[3] and A. Taufiq Asyhari[4]

[1]Department of Information and Library Science, Airlangga University, Surabaya, 60286, Indonesia

[2]Department of Anthropology, Airlangga University, Surabaya, 60286, Indonesia

[3]Department of Anatomy and Histology, Airlangga University, Surabaya, 60286, Indonesia

[4] School of Computing and Digital Technology, Birmingham City University, Birmingham, B4 7XG, United Kingdo m

[*]Corresponding Author: Imam Yuadi. Email: imam.yuadi@fisip.unair.ac.id

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Abstract: The size, shape, and physical characteristics of the human skull are distinct when considering individual humans. In physical anthropology, the accurate management of skull collections is crucial for storing and main- taining collections in a cost-effective manner. For example, labeling skulls inaccurately or attaching printed labels to skulls can affect the authenticity of collections. Given the multiple issues associated with the manual identification of skulls, we propose an automatic human skull classification approach that uses a support vector machine and different feature extraction methods such as gray-level co-occurrence matrix features, Gabor features, fractal features, discrete wavelet transforms, and combinations of features. Each underlying facial bone exhibits unique characteristics essential to the face's physical structure that could be exploited for identification. Therefore, we developed an automatic recognition method to classify human skulls for consistent identification compared with traditional classification approaches. Using our proposed approach, we were able to achieve an accuracy of 92.3–99.5% in the classification of human skulls with mandibles and an accuracy of 91.4–99.9% in the classification of human skills without mandibles. Our study represents a step forward in the construction of an effective automatic human skull identification system with a classification process that achieves satisfactory performance for a limited dataset of skull images.

Keywords: Discrete wavelet transform; Gabor; gray-level co-occurrence matrix; human skulls; physical anthropology; support vector machine

1 Introduction

1.1 Background and Motivation

Researchers in digital forensics commonly deal with a series of activities, including collect- ing, examining, identifying, and analyzing the digital artefacts required for obtaining evidence regarding physical object authenticity [1]. Several research challenges are associated with the digital forensic attributes found during physical anthropology investigation. One prevalent example is the management of skull collections in museums, which will benefit future research and education. A skull cataloging and retrieval system is a major component of skull collection management. Within this system, skulls with lost labels can be identified via an investigation process. This process includes labeling the collection in the form of a call number attached to each skull. This ensures that the skulls belong to a specific collection and facilitates their identification. This is equally important for proper documentation, development, maintenance, and enhancement of existing collections and making them available to curators who want to use them according to classification standards [2].

However, the utilization of ink streaks on skulls to apply an alphanumeric code can damage the authenticity of the skull as a study material. Hence, skull collection management necessitates a certain approach to maintain the authenticity of the collection and avoid damage through the use of chemicals. Attaching stickers with the call number is an alternative. However, this method also has drawbacks because stickers can become loose, fall off, and become fixed to other skulls.

Therefore, it is challenging to increase the number of new skull collections because of diffi- culties associated with their storage and collection. Skulls can include those separated from the mandible. Labelling errors are a major problem when human skulls and other skeletal collections in an anthropology forensics laboratory are ink out. Apart from the loss of labels attached to new bone collections, the mixing of old bone collections with new bones and high usage factors are challenges that must be overcome in skull collection management.

The use of digital cameras by anthropologists and other researchers to classify human bones is currently limited to manual investigation and comparison. Although some previous studies have applied automatic methodologies, such as machine learning, to identify human skulls, the majority of the samples were obtained via computerized tomography (CT) scans of living participants. These samples have limited relevance with respect to the analysis of skulls of dead subjects, as required in physical anthropology forensics.

1.2 *Contributions of This Work*

In this study, we investigate a digital forensics approach for the physical anthropological inves- tigation of skulls of dead humans based on their specific characteristics. Our main contributions are as follows. First, the significance of this work lies in the application of machine learning and data analytics knowledge to the new domain of physical anthropology collection management and addressing its unique challenges. Second, given the aforementioned problems introduced by manual labeling techniques, this study aims to evaluate the relevant contrasting features of human skulls and build skull-based identities from various positions via automatic classification. Third, our work proposes automatic classification of the skull beneath the human face that would allow curators to identify features based on skeletal characteristics. This technique would potentially assist in the management of museum collections or the laboratory storage of skulls; skulls could be identified without being manually marked or labeled, thereby maintaining their authenticity.

This study is inspired by face recognition technology. The structure of the mandible, mouth, nose, forehead, and the overall features associated with the human skull can be recognized using various means and properties. Based on the availability of these properties, face recognition can be conducted by comparing different facial images and classifying the faces using a support vector machine (SVM). The study [3] has applied SVMs to identify human faces, achieving face prediction accuracy rates of >95%. These studies applied different feature processing methods to acquire relevant statistical values before classification. Specifically, Benitez-Garcia et al. [4]

and Hu [5] applied the discrete wavelet transform (DWT) for feature extraction to identify a human face. Eleyan [6] used the wavelet transform, whereas Dabbaghchian implemented the discrete cosine transform (DCT) for human face analysis [7]. Krisshna et al. [8] used transform domain feature extraction combined with feature selection to improve the accuracy of prediction. In contrast, Gautam et al. [9] proposed image decomposition using Haar wavelet transforms through a classification approach in which the quantization transform and the split-up window of facial images were combined. Faces were classified with backpropagation neural networks and distinguished from other faces using feature extraction when considering a grayscale morphology. In addition, a combined feature extraction of Gaussian and Gabor features has been applied to enhance the verification rate of face recognition [10].

As observed in the present study, the effective combination of different feature filters is a step forward in using machine learning to conduct investigations in physical anthropology and its sub-areas. Researchers in the physical anthropology field often focus on analyzing the data characteristic obtained from the skulls of dead humans; this characteristic has rarely been found in previous studies on automatic face recognition. Therefore, this work offers a new perspective on the application of machine learning to physical anthropology and tackling its challenges, i.e., the limited physical collection of skulls of dead humans, variation in the completeness of skull construction, and deterioration of the skull condition over time. All these challenges are obstacles to the training of appropriate machine learning techniques and obtaining appropriate feature extraction is the key to achieve the learning objective, successful facial classification.

The remaining sections of this manuscript are as follows. Section 2 presents related works. Section 3 discusses the skull structure that provides the initial information for skull classification. Section 4 presents our main research approach and contribution to developing a machine learning- based automatic classification platform for classifying human skulls in physical anthropology. Section 5 reports our experimental results and validates our research approach. Finally, we summarize the main results of this research and directions of our future work in Section 6.

2 Related Works

There is increasing demand for an image classification system that can perform automatic facial recognition tasks [11–13]. Several studies have investigated facial recognition and facial perception. Automatic facial processing [11] is a reliable method and realistic approach for facial recognition. It benefits from the use of deep neural networks [12], dictionary learning [13], and automatic partial learning. These tools can be utilized to create a practical face dataset using inex- pensive digital cameras or video recorders. Several studies have also addressed human recognition based on various body images captured using cameras.

Elmahmudi et al. [14] studied face recognition through facial rotation of different face components, i.e., the cheeks, mouth, eyes, and nose, and by exploiting a convolutional neural network (CNN) and feature extraction prior to SVM classification. Duan et al. [15] investigated partial face recognition using a combination of robust points to match the Gabor ternary patterns with the local key points. Several studies [16–18] have used CNNs to extract complementary facial features and derive face representations from the layers in the deep neural network, thereby achieving highly accurate results.

Furthermore, Chen et al. [16] applied similarity learning using a polynomial feature map to represent the matching of each sub-region including the face, body, and feet to investigate the similarity learning for person re-identification based on different regions. All the feature maps were then injected into a unified framework. This technique was also used by Wu et al. [17], who combined deep CNNs and gait-based human identification. They examined various scenarios, namely cross-walking and cross-view conditions with differences in pre-processing and network architecture. Koo et al. [18] studied human recognition through a multimodal method by analyzing the face and body, using a deep CNN.

A previous anthropology study [19] provided complete information for facial identification by investigating skull objects in different positions. In forensic anthropology, experts use bones and skulls to identify missing people via facial reconstruction and to determine their sex [20]. The identification of craniofacial superimposition can provide forensic evidence about the sex and specific identity of a living human. Furthermore, tooth structure provides information about food consumed. Craniofacial superimposition is based on a skeletal residue, which can provide forensic artefacts prior to identification. Therefore, the skull overlay process is applied by experts to examine the ante-mortem digital figures popular in skull morphology analysis [21].

The so-called computational forensics method is a specific to the forensic anthropology approach [22]. In this area of research, Bewes et al. [23] adapted neural networks for determining sex on the basis of human skulls using data obtained from hospital CT scans. Furthermore, an automatic classification method for determining gender was developed by Walker [24], who investigated and visually assessed modern American skulls based on five skull traits. He used discriminant function analysis to determine sex based on pelvic morphology. He evaluated sexual dimorphic traits to determine sex. By using a logistic model, it can be seen that the classification accuracy rate is 88% for modern skulls with a note that a negligible sex bias of 0.1% exists. Another study on the skulls of white European Americans was conducted by Williams and Rogers [25], who accurately identified more than 80% of skulls. Angelis [26] developed another method to predict soft face thickness for face classification.

As observed in most of the above studies, automatic face recognition is mainly focused on the analysis of data obtained from living humans, be it in the form of digital camera or CT images. Even though the physical characteristics for facial identification and computational forensics for gender classification have been investigated in the anthropology literature, automated digital tools that are robust in terms of facial identification appear to be lacking. Thus, this work is a step forward in developing an automated tool by incorporating machine learning and knowledge about robust features.

3 Skull Structures

In principle, the facial skeleton or viscerocranium comprises the anterior, lower, and skull bones, namely, facial tissue, and other structures that form the human face. It comprises various types of bones, which are derived from the branchial arches interconnected among the bones of the eyes, sinuses, nose, and oral cavity and are in unity with the calvarias bones [27]. Naturally, the viscerocranium encompasses several bones, which are illustrated in Fig. 1 and are organized as follows.

1) Frontal—This bone comprises the squamous, which tends to be vertical, and the orbital bones, which are oriented horizontally. The squamous forms part of the human forehead, and the orbital part is the part of the bone that supports the eyes and nose.
2) Nasal—The paired nasal bones have different sizes and shapes but tend to be small ovals. These bones unite the cartilage located in the nasofrontal and upper parts of the

lateral cartilages to form the human nose and consists of two neurocraniums and two viscerocraniums.

3) Vomer—The vomer bone is a single facial bone with an unpaired midline attached to an inferior part of the sphenoid bone. It articulates with the ethmoid, namely, the two maxillary bones and two palatine bones, forming the nasal septum.
4) Zygomatic—The zygomatic bone is the cheekbone positioned on the lateral side and forms the cheeks of a human. This bone has three surfaces, i.e., the orbital, temporal, and lateral surfaces. It articulates directly with the remaining four bones, i.e., the temporal, sphenoid, frontal, and maxilla bones.
5) Maxilla—This is often referred to as the upper jaw bone and is a paired bone that has four processes, i.e., the zygomatic, alveolar, frontal, and palatine processes. This bone supports the teeth in the upper jaw but does not move like the lower jaw or mandible.
6) Mandible—The mandible is the lower jaw bone or movable cranial bone, which is the largest and strongest facial bone. It can open and close a human’s mouth. The mandible has two basic bones, i.e., the alveolar part and the mandible base, located in the anterior part of the lower jaw bone. Furthermore, it has two surfaces and two borders [28].

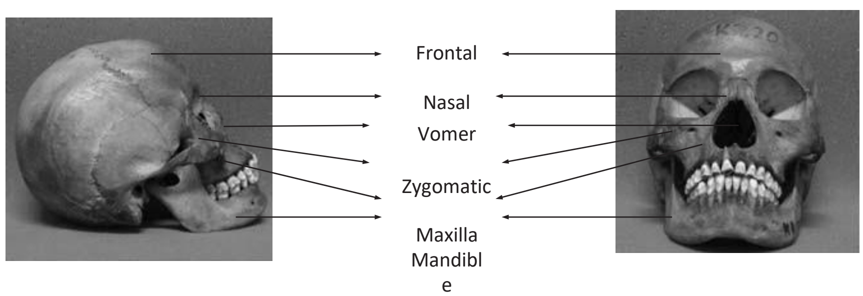

Figure 1: Structure of a human skull

4 Research Approach

In the following subsections, we describe the systematic design steps adopted for developing an automatic intelligent human skull recognition system using data collection and processing, feature extraction filters, and skull classification to obtain maximum prediction accuracy.

4.1 *Tools and Software Platform*

We used hardware and software platforms that would allow us to meet the objectives of this study and conduct forensic tests on human skulls. First, we used a DSC-HX300 digital camera (Sony Corp., Japan) equipped with high-resolution Carl Zeiss lenses for obtaining the skull images. Then, we applied Matlab software version R2013a to convert the image data into a numeric form. Finally, we implemented an SVM classifier with Eclips SDK in Java for skull classification. To run the aforementioned software, we used a personal computer with the following specifications: Intel Core i5 Processor equipped with 8 GB of RAM, using the Windows XP operating system.

4.2 *Framework*

Fig. 2 presents the framework used for digital forensics when investigating the characteristics of human skulls in this work. It indicates the step-by-step investigation procedures, beginning with the digitalization of skull data and ending with skull identification. This process is explained in detail below:

1) Digitizing human skulls: In the first step, skulls were digitized by taking their photos from various angles using a digital camera. Thus, images of the face or front, left, right, bottom, and top areas could be obtained. The obtained results were then documented and saved as digital image files. Fig. 4 presents the region of interest (ROI) of an image sample. This figure shows the skull area corresponding to a set of pixels, where (i,j) denotes a spatial location index within the picture.
2) Feature extraction: This step was conducted to obtain certain values from skull images via feature filtering or extraction based on pixel characteristics and other criteria. Various feature filters were applied to compare the accuracy rates of the implemented filters. This was the major image processing activity prior to the segmentation and classification steps. We considered four different feature-filtering techniques to determine the relevant features and extract their corresponding values from the images. We conducted a texture analysis approach using this feature filter before classifying the human skulls. Four feature filters were separately applied to obtain a different accuracy rate for classification. For this study, we used 22 feature-level, co-occurrence matrices (GLCM), 12 features of the discrete wavelet transform (DWT), 48 Gabor features, and 24 fractal features or segmentation-based fractal texture analyses (SFTA). In total, we used 106 features. The filters were applied to analyze 24 images of skulls at various rotation angles (from 1° to 360°); each image was extracted with these filters to obtain a different statistical decomposition. Therefore, each skull image produced a minimum of 360 images to be extracted through the deployment of various filters before classification.
3) Classification: The support vector machine (SVM) is a widely applied method developed by Awad and Khanna [29] for data classification and regression. This method can maximize the distance between several data classes even when applied to a high-dimensional input space. It also has the ability to process and group images based on patterns, which is an advantage of the SVM, especially against the drawback of dimensionality. Furthermore, the SVM can solve the problem of limited training and can minimize the parameter associated with its structure based on its ability to work on nonlinear problems by adding a high- dimensional kernel [30]. The SVM works by finding the best hyperplanes to classify the different space classes in the input space. Classification can be conducted by finding a hyperplane that separates groups or classes through margins and maximum points. There- fore, it can run on nonlinear kernel data with nonlinear kernel functions by mapping the product point from lower to higher dimensions. In this study, radial basis function (RBF)- based kernels were selected to build a nonlinear classifier for identifying 24 different types of skull. More specifically, we applied the RBF-based kernel function used in a previous study to build this SVM-based classifier [31], i.e., $K_{RBF}(x_i, x_j) = \exp(-\gamma \| x_i - x_j \|^2)$. Here, $\gamma > 0$ and $\|.\|$ denotes the kernel-spreading coefficient and the Euclidean norm applied to the difference between two data points, x_i and x_j. The value of γ was optimized via a coarse grid search by transforming the original data to the feature space.

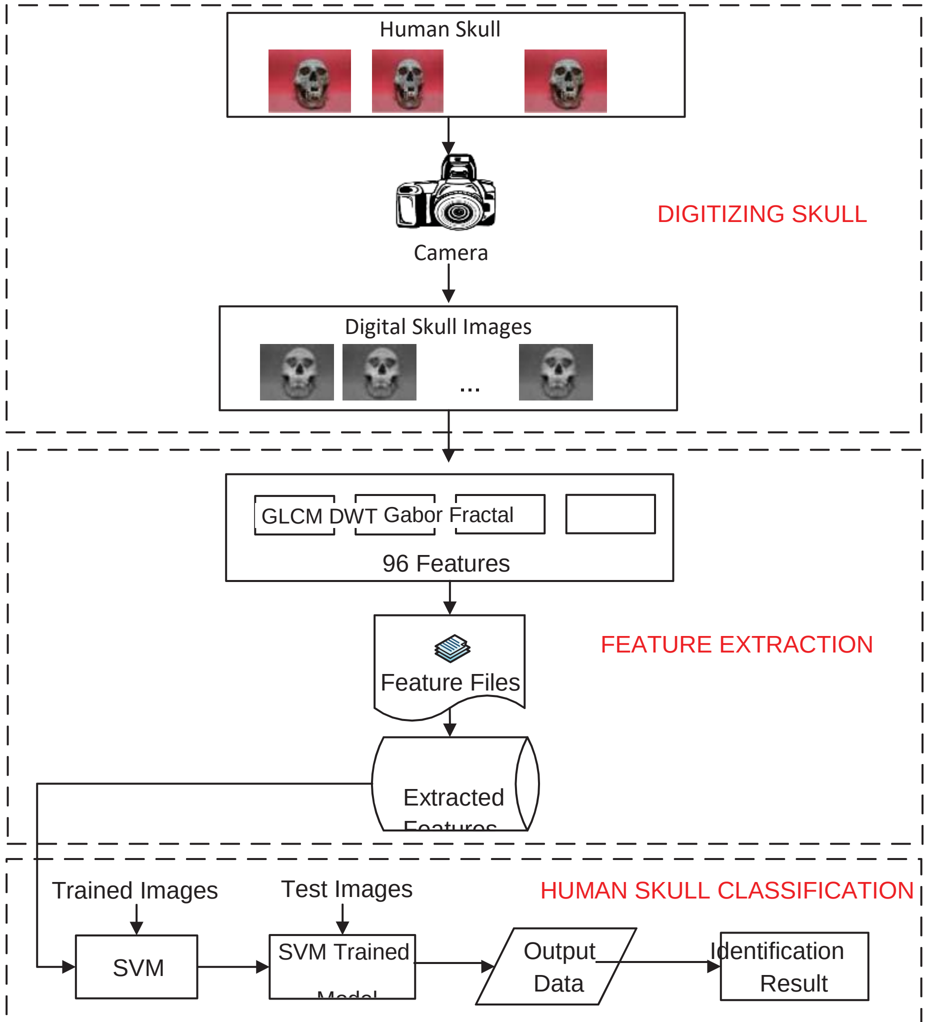

Figure 2: Framework used for digital forensics when investigating the characteristics of human skulls

4.3 Feature Extraction

Feature extraction involves the transformation of data. The derivative values from original data are transformed into variable data with statistical values that can be further processed. Here, we used the following techniques for feature extraction.

1) GLCM is a popular filter for texture analysis. It captures information regarding the gray- value spatial distribution in an image and the image texture's corresponding frequency at given specified angles and distances. Feature extraction using GLCM is conducted based on the estimated probability density function of a pixel using a co-occurrence matrix along with its pixel pairs, where features can be statistically and numerically quantified [32]. Four angular directions are considered during matrix generation for feature extraction. Specifi- cally, the statistical characteristics are calculated in the 0°, 45°, 90°, and 135° directions. Fig. 3 presents direction (horizontal and vertical orientations) as a spatial representation based on different reference pixels. Let us assume that reference pixel i is defined with

a 45° orientation based on which an adjacent pixel can be located. The direction of the pixel is calculated when considering pixel j next to pixel i, as demonstrated by Tsai et al. [33]. Following this work, Fig. 4 illustrates the ROI of human skulls showing the pixels generated by GLCM in gray color, as captured by Eq. (1).

$$R = \sum_{(i,j)\in ROI} 1. \quad (1)$$

Thus, pixels are labeled as “1” if they belong to the ROI and “0” otherwise. From Eq. (1), we can obtain the predictable values from the normalized GLCM.

$$GLCM\,(i,j) = \frac{1}{\sum_{(i,j)} Img(i,j)}\,Img(i,j). \quad (2)$$

Here, (i,j) denotes the index of the pixel in the image, and Img (i,j) denotes the probability of the pixel index (i,j). GLCM can generate 22 texture features, as explained in detail by Tsai et al.

2) Wavelet features. A digital image comprises many pixels that can be represented in a two-dimensional (2D) matrix. Outside the spatial domain, an image can be represented in the frequency domain using a spectrum method called the DWT. In several studies (e.g., [34,35]), the feature sets are focused on 2D-scale wavelets because of their underlying functions. The feature filter direction follows subsampling with two factors, and each sub- band is equivalent to the output filters, which contain several samples compared with the main 2D matrix. The filtered processing outputs are considered to be the DWT coefficients. This filter set of DWT coefficients, as shown in Fig. 4, contains 12 statistical features that include kurtosis (HH, LH, HL, and LL sub-bands), standard deviation, and skewness.
3) Gabor features. Gabor filters are shaped through dilation and rotation in a single kernel with several parameters. The corresponding filter function is used as a kernel to obtain a dictionary filter for analyzing the texture images. The 2D Gabor filter has several benefits in a spatial domain, such as a number of different scales and orientations allows for feature extraction and also, invariance for rotation, illumination, and translation involving the Gaussian kernel function [36] modulated by complex sinusoidal waves [37,38]. Inspired by these works, we used the function in Eq. (3) to extract human skull images.

$$GG(x,y,\theta,f) = \exp\left(-\frac{1}{2}\left[\left(\frac{x^r}{Sx}\right)^2 + \left(\frac{y^r}{Sy}\right)^2\right]\right)\cos(2\pi f x^r). \quad (3)$$

Here, parameter x^r is expressed as $x\cos(\theta) + y\sin(\theta)$, and y^r is expressed as $y\cos(\theta) - x\sin(\theta)$. S_x and S_y denote the variances along the x and y axes, respectively. Finally, parameter f denotes the frequency of the sinusoidal function, and θ represents the orientation of the Gabor filter. Subsequently, the following numerical values were considered as part of Gabor feature extraction: Sy = 4; Sx = 2; f = 2, 4, 8, and 16; and θ = 0, π/2, π/4, and 3π/4. Then, we extracted and acquired all 48 Gabor features from each image.
4) Fractal features are considered when evaluating images with similar textures. Features are obtained from the fractal dimensions of the transformed images obtained from the boundary of segmented image structures and grayscale images. Fractal features can be used to compute the fractal dimension for any surface roughness. Furthermore, they can be used to evaluate the gray image and compare various textures. Fractal dimensions can

be realized as a measure of irregularity or heterogeneity. If an object has self-similarity properties, then the entire set of minimized subsets will have the same properties. In this study, the boundaries of the feature vector were used to measure fractals. The measurement is represented as O (x, y), and can be expressed as follows:

$$O(x,y) = \begin{cases} 1 & \text{if } (x', y')\ N_4[(x,y)]: \\ & I_b(x', y') = 0 \wedge I_b(x', y') = 1, \\ 0 & \textit{otherwise}. \end{cases} \quad (4)$$

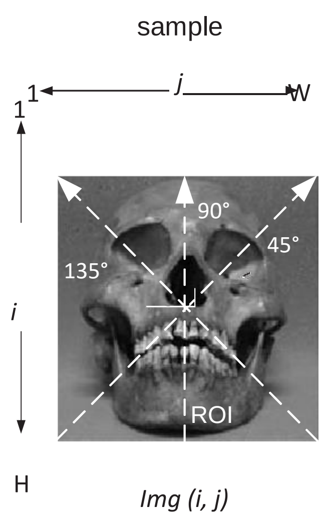

Figure 3: Estimation of texture orientation from a skull image. The pixel of GLCM (n, m) from four different regions of interest (ROIs), where the spatial location of the skull image is indicated by i and j. At a point, pixel separation (W and H) is applied as W = 0 and H = 1 to obtain the number of gray-level pixels n and m

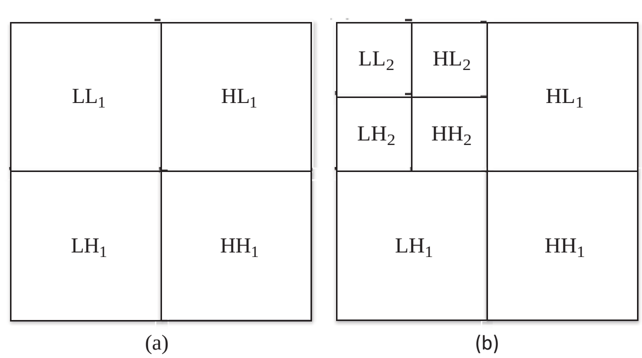

Figure 4: Discrete wavelet transform image decomposition for (a) one and (b) two levels of resolution

This measurement function is similar to the one in Costa et al. [39], except, instead of N_8 (x, y), N_4 [(x, y)] is used to denote a grayscale skull image that has a vector size threshold of 4 in related to (x, y) in a group of pixels. For binary decomposition, they applied a thresholding mechanism to the input image. In this study, we applied a four-connected pixel in the case of threshold segmentation to (x, y). Thus, 24 features could be extracted.

4.4 Data Samples

In this study, human skulls were categorized based on their mandibles. We validated and compared the samples' unique characteristics (not only skulls with mandibles but also those without mandibles), as shown in Fig. 5. To obtain fair research results, we considered 24 skulls with mandibles and 24 skulls without mandibles to define our target classes for classification. We then took pictures of the samples using the aforementioned digital camera. The skulls were obtained from the Physical Anthropology Laboratory at Airlangga University. The original skull images can be accessed from http://fisip.unair.ac.id/researchdata/Skulls/.

Figure 5: Skulls with a mandible (top) and without a mandible (bottom)

We experimented with seven different angles for the images of skulls with and without mandibles: front, top, and back angles, as well as 45° right-angle, 45° left-angle, 90° right-angle, and 90° left-angle rotations. Then, we rotated the image step-by-step by 360°; each degree of rotation produced one sample image that was stored as the input sample for machine learning. For example, the front angle was rotated by 360°, and thus we analyzed 360 data samples. Subsequently, we converted all the images to grayscale in jpeg (jpg) format, set a pixel size of 53 × 40 for each image, and set the file size to 4 kb. Tab. 1 details the 360 processed sample images for each skull image that were obtained via rotation. The total number of images used in this experiment was 8,640. We classified 24 skull images as the target class of classification. The result of a given experiment was the average of ten rounds of the given experiment. For each round of an experiment, a set of 300 images was uniformly sampled.

In this experiment, it was conducted by dividing into training and testing data with a ratio of 2:1. There were ten sets and each set comprised 300 images selected for training data and another 150 images for test data.

Table 1: Data sample of human skulls

Class	Sample	Pixels	Size	Total Data
Skull with mandible		53 × 40	4.00 kb	8,640
Skull without mandible		53 × 40	4.00 kb	8,640

4.5 *Research Limitation*

The limitations of this study were difficulty in obtaining experimental data and using camera settings to ensure the same resolution when capturing skull images. Another limitation was that seven different angles were considered to perform comparisons between skulls with and without mandibles. Because of the difficulty associated with finding research objects, this study focused on the classification of 24 skulls, which were all in an incomplete condition, especially those that had teeth attached.

5 Experimental Results

As described previously, we considered two different digital skull images: skulls with mandibles and skulls without mandibles. We first applied each feature extraction filter separately to clearly understand the factors influencing the experimental results. This process was followed by combin- ing all the feature extraction filters. The following subsections discuss the application of filters and obtained classification accuracy.

5.1 *Experiment i: Identification of Skulls with Mandibles*

In Experiment I, we considered the images of human skulls with mandibles and examined them from different angles as shown in Fig. 6. Prior to classification, the feature extraction tech- niques (see Section 4) were applied to the images, and Matlab was used to obtain the numerical values of the generated features. Then, we exported the numerical values on the basis of a filter set into a MySQL database for future referencing. Subsequently, we performed image-driven skull classification using the SVM implemented in a Java programming environment to compute the accuracy of the classification task on the basis of a given set of features. We considered all the individual treatments of each feature extraction filter and the combined effect. The accuracy rates of predicting the skulls from different angles are presented in Tab. 2.

The detailed steps of this experiment were as follows.

(1) Step 1: We used 24 sets of images extracted using various extraction filters. Each resulting set of images contained 360 transformed images obtained by rotating the original image via one-degree rotation per step. From all the available images, we selected 200 skull images as training data and 100 skull images as testing data. Our four extraction filtering techniques were then applied for feature extraction.

(2) Step 2: We ran the SVM to predict human skulls with mandibles using the four filtering techniques individually and then a combination of all four filters.

(3) Step 3: We conducted a series of image testing steps on the basis of the appropriate model constructed in Step (2) for human skulls with mandibles.
(4) Finally, we repeated Steps (1)–(3) nine more times (for a total of ten replicates) and obtained the average performance.

The classification of skulls differed in accuracy across the seven angles of interest. Evidently, each filter had a different accuracy even though the within-filter results were numerically stable. Gabor feature extraction was stable, i.e., higher than 90%, making it the superior feature filter among the four considered techniques. In contrast, the DWT filter resulted in an accuracy rate as low as 89.73%. Conversely, the GLCM, Gabor, and fractal filters consistently achieved a classification accuracy >98%. With prediction accuracies that were mostly >90%, all four filters are promising tools for assisting the SVM in automatically classifying human skulls for physical anthropology applications.

(a) (b) (c) (d) (e) (f) (g)

Figure 6: Various angles used for depicting images: (a) front angle, (b) 45° right-angle rotation, (c) −45° left-angle rotation, (d) 90° right-angle rotation, (e) −90° left-angle rotation, (f) top angle, and (g) back angle

Table 2: Accuracy of prediction (%) for human skulls with mandibles

Filter	Front	−45° left	45° right	−90° left	90° right	Back	Top
GLCM	98.07	99.90	99.75	99.76	99.81	99.74	99.99
DWT	92.37	94.05	89.73	94.01	93.77	94.97	97.05
Gabor	99.24	99.55	99.21	99.43	99.45	99.44	99.69
SFTA	99.33	99.21	99.00	98.98	98.57	98.68	99.51
All	99.52	99.57	99.53	99.57	99.39	99.46	99.80

5.2 *Experiment II: identification of Skulls Without Mandibles*

We also conducted identifications of skulls without mandibles to evaluate the robustness of our classification system.

Tab. 3 presents the performance accuracy of the five filters for human skulls without mandibles (we selected 24 out of 99 available samples in this table). The classification results obtained using the SVM varied according to the different feature extraction filters. Overall, the GLCM filter offered superior prediction capabilities, achieving higher than 99% accuracy for all the angular positions of the skulls. The discrete wavelet transform had the lowest accuracy. Almost all filters had prediction accuracies >90%, except for DWT at 45° left (88.36%). The prediction accuracy was 99.61% when we combined the features from all the filters.

Table 3: Accuracy prediction (%) for human skulls without mandibles

Filter	Front	−45° Left	45° Right	−90° Left	90° Right	Back	Top
GLCM	99.95	99.92	99.88	99.87	99.86	99.87	99.95
DWT	91.45	88.36	92.18	90.58	93.43	95.18	96.24
Gabor	99.29	99.19	99.39	99.27	99.34	99.65	99.63
SFTA	98.97	99.00	98.46	98.82	98.69	99.42	99.48
All	99.61	99.56	99.56	99.32	99.46	99.50	99.72

In automatic human skull classification, the implementation of feature extraction and the combination of different feature filters play a significant role in the accumulation of relevant features. Each filter can produce several features. A classification system with diverse results can be produced by using four different filters and combining all generated features. For example, in this study, the use of GLCM comprising 22 features resulted in a classification accuracy rate of 99.86–99.95% depending on the angular position of the skull. Conversely, DWT feature extraction had a much lower accuracy rate of 88.36–96.24%.

5.3 *Experiment III: Different Resolutions for Skull Classification*

We also used different electronic imaging devices to compare and validate the results of the previous experiments in which we used a high-resolution camera; however, in Experiment III, we used a mobile camera (NOKIA 3.1 plus) with a lower resolution. We used the same experimental approach but captured the skull front angle images with different lens sizes for camera resolutions of 2, 4, and 9 MP.

Tab. 4 presents the accuracies obtained when identifying human skulls using three different camera resolutions. The accuracy of predictions increased with increasing resolution. For example, a 2-MP camera resolution resulted in a prediction accuracy of 91.41% for GLCM, lower than those for a 4-MP resolution (93.17%) and a 9-MP resolution (97.83%).

Table 4: Accuracy prediction (%) for different resolutions

Filter	2 MP	4 MP	9 MP
GLCM	91.41	93.17	97.83
DWT	67.38	67.89	70.07
Gabor	88.48	91.50	93.55
SFTA	79.32	80.20	90.67
All	83.75	86.98	94.62

5.4 *Discussion*

Our experimental results indicate that the classification of skulls with mandibles was as accurate as that of skulls without mandibles. However, the required calculation time for processing the images of skulls with mandibles was shorter than that for skulls without mandibles.

This study extends the analysis and framework for the identification of human faces reported in previous studies [4,5,9], and [40,41] but uses a different approach to the classification of human skulls. The results from previous studies are summarized in Tab. 5 for further comparison of identification accuracy. The majority of these approaches achieved an average accuracy higher than 90%. The lowest accuracy was observed with the method used by Hu et.al (94.67%) [5]. Other studies exhibited much better accuracies, with averages >95%. The most accurate approach was obtained via research with CNNs [41], resulting in an accuracy of 98.43%. Other approaches, such as principal component analysis, Euclidean, and Gaussian mixture model [40], also exhibited a high accuracy. Nevertheless, our method of analyzing human skulls rather than the faces of living persons resulted in even higher accuracies. Using the framework presented in Fig. 2, we obtained a high classification accuracy when identifying skulls. Thus, our novel approach could be a promising application in digital forensics with respect to human skull identification.

Table 5: Results of different face recognition approaches

Research	Research object	Approach	Accuracy rate (%)
[4]	Live human face	PCA, sub-block processing	97.60
[5]	Live human face	PCA, dual-tree complex wavelet transform (DT-CWT), and single-tree complex wavelet transform (ST-CWT)	94.67
[9]	Live human face	Principal component analysis (PCA), particle swarm optimization (PSO)–SVM (PSO–SVM)	98.00
[40]	Live human face	PCA, Euclidean, Gaussian mixture model (GMM)	97.04
[41]	Live human face	CNNs	98.43
Our work	**Dead human skull**	SVM	99.50

Unlike human face recognition research, one of the major challenges associated with the present study was the acquisition of human skull data. This is because the skull is an inanimate object that must be moved to obtain data from various angles. This movement was achieved by manually turning the skull to appropriate angles to obtain images from various positions. This is highly challenging, especially when the skull is in an incomplete condition.

Moreover, variation in the amount of training data can impact the accuracy of the classifi- cation task. It is thus of interest to investigate how various training dataset sizes can affect the performance of SVM classification. The prediction accuracy rates for skulls with and without mandibles show that the amount of training and testing data affects the prediction accuracy. For example, with the GLCM filter, when we used only one training data item to predict skulls with mandibles, we obtained an accuracy rate of 18.33%. However, when we used 100 training data items, the accuracy rate was 97.03%. Thus, a greater amount of applied training data will result in a higher accuracy.

Skulls generally have one dominant texture and color but may have different shapes and sizes even if the skulls share ancestry. However, if the bones are buried in different soils (for example, clay or calcareous soils), they will have different colors.

In this forensic study, we applied a digital camera to digitize the skulls. The implementation of different digitizing tools will affect the level of accuracy, especially regarding image resolution. Therefore, in further research, we recommend the use of advanced digital technology capabilities such as, postmortem computed tomography (PMCT) and angiography, as well as X-rays.

This study focused on only 24 human skulls with mandibles and 24 skulls without mandibles because of the limitations and difficulties in obtaining sample data in physical anthropology. How- ever, we also conducted experiments on other skulls without mandibles (99 skulls) even though with some bone structures were incomplete when they were discovered. Therefore, we only focused on the classification of skull faces. Our results were similar to those obtained from Experiments III, although the level of accuracy was slightly higher than those in previous experiments.

6 Conclusion

We developed an automatic computerized digital forensics approach for human skull identification using feature extraction in tandem with an SVM. We applied a digital forensics framework to classify human skulls with and without mandibles. We tested four different feature extraction filters for feature extraction that resulted in different classification accuracies. GCLM achieved the maximum accuracy with features generated from Gabor and fractal features (>99%). In contrast, DWT features resulted in identification prediction accuracies <95%. The combination of the four feature extraction techniques produced an accuracy rate >99% for skulls both with and without mandibles. Thus, every human skull has unique features that can be used to distinguish its identity in forensics applications, especially in physical anthropology collection management.

We can identify several future directions for research related to skull identification. For future work, it will be necessary to optimize the combined feature extraction and classification method and to explore other feature extraction techniques and classification methods for performance comparisons. Utilizing additional skull data when using the CNN method could be the main focus for such future research. Furthermore, the determination of the age and gender associated with the skulls will greatly assist researchers in identifying humans who disappeared due to natural disasters or who were victims of criminal activities.

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