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Fast and Accurate Spelling Correction Using Trie and Damerau-Levenshtein Distance Bigram

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Abstract

This research was intended to create a fast and accurate spelling correction system with the ability to handle both kind of spelling errors, non-word and real word errors. Existing spelling correction system was analyzed and was then applied some modifications to improve its accuracy and speed. The proposed spelling correction system is then built based on the method and intuition used by existing system along with the modifications made in previous step. The result is a various spelling correction system using different methods. Best result is achieved by the system that uses bigram with Trie and Damerau-Levenshtein distance with the word level accuracy of 84.62% and an average processing speed of 18.89 ms per sentence.

Keywords: *damerau-levenshtein distance, bigram, spelling correction, trie*

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1. Introduction

Language is an arbitrary sound symbol system, which was used by society's member to work, interact and self identification [1]. There are two forms of language, written and spoken. Writing has an important role in conveying the written meaning. Errors in the writing may cause the meaning to be unconveyed or even distorted into different meaning.

Spelling correction is a task for detecting and fixing any spelling errors. There are two kinds of spelling errors, a real word error and non-word error [2]. Real word error is an error that causes a certain word to transform into other word with the same or different meaning. While a non-word error is an error that causes a certain word to transform into a meaningless word.

Existing research on spelling correction is generally conducted only on one kind of the spelling errors [3-6]. The methods used to handle each kind of spelling error quite differ from one another. Most spelling correction system tackles each problem separately. The main purpose in this research is to create a fast and accurate spelling correction system with the ability to fix both kinds of spelling errors.

Some of the relevant research used as main reference are done by Setiadi [3] and Verberne [4]. In this research, Setiadi showed an alternative in optimizing the performance of spelling correction in term of speed and accuracy. Setiadi reduced the edit distance computation using a certain word length rule and using simple assumption to add extra value or rank to a certain word correction candidate. Verberne uses trigram to handle the real word error and split sentence into parts in trigram form before checking and correcting any spelling error.

Existing system is then modified in this research to improve its accuracy and speed. Trie data structure is added in Setiadi's system to represent known vocabulary list which is supposed to improve processing speed on word validity check and word correction candidate generation. Smoothing technique is added in Verberne's system, supposedly to reduce data sparsity problem. And a precomputation of edit distance is used to remove the recomputation of previously seen word (on generation of correction candidate word). Bigram is tried as an alternative to trigram in Verberne's system. The proposed system is built based on the method and intuition in the aforementioned system with the modifications made to improve its performance.

2. Research Method

There are some categories of spelling errors, such as substitution, deletion, insertion, transposition and split word [6]. In this research, all categories of spelling errors will be covered, except for split word error. Illustration for the spelling errors categories can be seen in **Error! Reference source not found.**

Substitution	Deletion
Supstitution	Deltion
Insertion	Transposition
Insaertion	Transpositino

Figure 1. Spelling errors categories

Edit distance method is used in the referenced system, as well as in this research. Edit distance is the operation cost needed to transform a word into another [7]. There are various other string comparison methods such as the Hamming distance, Longest Common Subsequence, Jaro Wrinkler distance, etc. The most generally known edit distance is Levenshtein distance. Levenshtein distance considers the cost for a certain operation such as deletion, insertion and substitution of characters in word. As such, it should be more suitable for spelling correction task. Another variation of Levenshtein distance is the Damerau-Levenshtein distance, which considers another operation cost, which is the transposition of adjacent letters in a word [7]. Based on [7], equation for Levenshtein distance can be seen in (1) and Damerau-Levenshtein distance in (2).

$$d_{a,b}(i,j) = \begin{cases} \max(i,j), & \text{if } \min(i,j) = 0, \\ \min \begin{cases} d_{a,b}(i-1,j) + 1 \\ d_{a,b}(i,j-1) + 1 \\ d_{a,b}(i-1,j-1) + 1_{(a_i \neq b_j)} \end{cases}, & \text{else} \end{cases} \quad (1)$$

$$d_{a,b}(i,j) = \begin{cases} \max(i,j), & \text{if } \min(i,j) = 0, \\ \min \begin{cases} d_{a,b}(i-1,j) + 1 \\ d_{a,b}(i,j-1) + 1 \\ d_{a,b}(i-1,j-1) + 1_{(a_i \neq b_j)} \\ d_{a,b}(i-2,j-2) + 1 \end{cases}, & \text{if } i,j > 1 \text{ \& } a_i = b_j - 1 \text{ \& } a_i - 1 = b_j \\ \min \begin{cases} d_{a,b}(i-1,j) + 1 \\ d_{a,b}(i,j-1) + 1 \\ d_{a,b}(i-1,j-1) + 1_{(a_i \neq b_j)} \end{cases}, & \text{else} \end{cases} \quad (2)$$

N-gram is a contiguous sequence of N item, which could be words, letters, syllables, or phonemes [2]. For example bigram (2-gram) is sequence that consist of two words sequence such as “salah satu”, “satu kota”, “kota besar”. The probability of a long sentence can be computed by splitting it into smaller parts and use the conditional probability rule to compute the overall probability. N-gram gives the highest accuracy value to all word gram level for similarity detection in stemming process [8]. In a spelling correction task, N-gram is used to set the probability of correction words. Based on [2], the general equation for N-gram probability can be seen in (3).

$$P(w_n | w_{n-N+1}^{n-1}) = \frac{C(w_{n-N+1}^{n-1} w_n)}{C(w_{n-N+1}^{n-1})} \quad (3)$$

In computing a probability, it gives zero to unseen events. Smoothing is a process of giving a certain probability value to unseen events by reducing the probability of seen events [2]. Smoothing is used to avoid the zero probability given by the language model. There are various

smoothing methods, such as Laplace, Good-Turing, Kneser-Ney, Add-K, Back-Off, Interpolation, etc. Smoothing method is usually combined to produce better result such as using Good-Turing and Interpolation [2]. In this research, combination of Laplace and Back-off is used as the smoothing method. Based on [2], Equation for Laplace smoothing can be seen in (4) and Back-off in (5).

$$P_{Laplace}(w_n) = \frac{C(w_n)+1}{N+V} \quad (4)$$

$$P_{Back-off}(w_n|w_{n-N+1}^{n-1}) = \begin{cases} P^*(w_n|w_{n-N+1}^{n-1}), & \text{if } C(w_{n-N+1}^{n-1}) > 0 \\ \alpha(w_{n-N+1}^{n-1})P_{Back-off}(w_{n-N+1}^{n-1}), & \text{else} \end{cases} \quad (5)$$

Perplexity is an intrinsic evaluation method for a language model. Perplexity of a language model is computed by inverting the probability from a test set (sentence) and normalized by the count of words [2]. By inverting the probability, it means that the higher the probability of a given test set, the lower is the perplexity. Low perplexity means that the applied language model is better, although it doesn't guarantee the increase in accuracy for extrinsic evaluation. Based on [2], equation for Perplexity can be seen in (6).

$$PP(W) = \sqrt[N]{\prod_{i=1}^N \frac{1}{P(w_i|w_1...w_{i-1})}} \quad (6)$$

First step of this research is to build the referenced existing spelling correction system by using the same programming language as the proposed system. This was done in order to accurately compare the referenced spelling correction system against the proposed one as programming languages may vary from one another in term of performance. The referenced spelling correction can be accurately built based on the explanation in the respective paper and with the help of source code (of different language) generously shared by the referenced system's author.

Data in this research is an online news article taken from Kompas (kompas.com). Data is taken by crawling the site using a crawler built with the help of an external software library. The amount of data crawled and used in this research is 5000 online news articles. The crawled news articles are from 2nd to 12th March 2016. The crawled news category count can be seen in Table 1.

Table 1. News Article Category Distribution

Category	Amount
Regional	867
Megapolitan	830
Nasional	714
Entertainment	393
Bola	365
Ekonomi	355
International	294
Automotive	228
Travel	204
Property	184
Sports	142
Techno	140
Health	136
Female	99
Science	34
Education	15
TOTAL	5000

The characteristics of Setiadi's system that yielded the best result in term of performance is that the edit distance computation is pruned or reduced using a simple rule [3]. The rule used is dismissing computing edit distance if the correction candidate word has a

length of less or more than 1 compared against the mistyped word. This method helps to speed up processing time. An alternative for more efficient computation is by using a Trie data structure to represent the known words. Computing edit distance on words represented in a Trie data structure can greatly improve the processing speed because Trie data structure groups words based on its prefix [8]. Normally, edit distance is computed on every word with the same prefix. By using a Trie data structure, words with the same prefix will only be computed once. Validation of a word should also be faster since the time required for a string matching is $O(n)$ for n as the longest string length [8]-[10]. Illustration for Trie data structure can be seen in Figure 2.

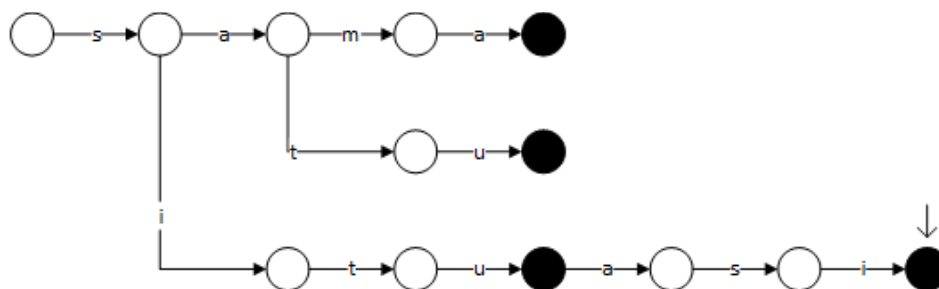


Figure 2. Trie Data Structure Illustration for Word: "sama", "satu", "situasi"

Setiadi also used a bayes theorem to make a simple assumption to add an extra value or rank to a certain correction candidate word. The assumption is that a word with longer length is more likely to have the need to correct its mistyped word when compared with another correction candidate word of shorter length. Although, this simple assumption yielded the best result than when without using it in Setiadi's research, we'll try and see if it also yields a good result when using our data.

In Verberne's system, the generation of correction candidate words was conducted everytime it detected a real word error. A word might be detected as an error multiple times in a sentence, hence the system will regenerate (recompute edit distance) correction candidate words of the same words multiple times. We can precompute this process to speed up processing time since the word is limited to only known words in case of a real word error. Bigram is experimented as an alternative to Trigram in Verberne's system to see its impact on the performance.

The proposed system is built by combining the referenced system along with its modification to improve the overall performance. Setiadi's system accepts single word as input, while Verberne system accepts a whole sentence but splits them into trigram parts and corrects it separately. The proposed system will accept sentence as input then splits them into n-gram parts, corrects it separately and combines it back into a whole sentence using the chain rule probability.

The language model of the data is evaluated by computing the perplexity of each model (unigram, bigram, and trigram). Categories of the test made against the system is the accuracy rate, overall processing speed, and false-positive rate. Test data for the testing of the perplexity is a different news article taken from a random source, which is different from the ones used as the main data for the system. Perplexity is computed as an average of overall perplexity across all sentences in the article. Test data for the other test is a 50 sentences (475 words) data taken from a news article of random source which is modified to contain a real word error (58 error words), a non-word error (50 error words), and a combination of both (104 error words) (3 sets).

3. Results and Analysis

3.1. Perplexity

Perplexity result for language model using Equation (6), can be seen in Table 2. The lowest result is achieved by using unigram. This shows that there is a high rate of data sparsity in the used data set. Trigram yield the highest value, which shows that the spelling correction

system that uses trigram might not perform well than that using bigram. To reduce the data sparsity, a smoothing technique is added to the spelling correction system.

Table 2. Perplexity Test Result

N-Gram	Average Perplexity
Unigram	21834.7362
Bigram	170415.4672
Trigram	84060875.6503

3.2. Referenced System

The test result for the referenced system can be seen in Table 3 and Table 4.

Table 3. Setiadi's System Test Result Comparison

Test Categories	Setiadi	Setiadi (Modified)
Sentence Accuracy (%)	70	78
Word Accuracy (%)	76	84
False-Positive (%)	1.6	1.6
Time Spent (s)	24.35	0.49
Average Time Spent (ms)	487.01	9.71

Table 4. Verberne's System Test Result Comparison

Test Categories	Verberne	Verberne(Modified)
Sentence Accuracy (%)	6	26
Word Accuracy (%)	5.17	29.31
False-Positive (%)	0	1.09
Time Spent (s)	1.35	0.37
Average Time Spent (ms)	26.99	7.46

Based on the test result of Setiadi's system, there is a significant change in term of processing speed when using a Trie data structure. The achieved accuracy is also increased although it's not that significant. This shows that the use of simple assumption as mentioned previously doesn't perform well on our data. Based on the test result of Verberne's system, the processing speed increases when the edit distance is precomputed beforehand. Accuracy is also increased when a smoothing technique is added into it. Although the achieved accuracy is still considered low, it shows that the smoothing technique is able to reduce the data sparsity which in turn improves the accuracy. The smoothing technique used is the Add-1 Laplace smoothing (4) in combination with Stupid Back-off (uses 0.4 as α) (5).

3.2. Proposed System

The proposed system was built by combining the method in both of the referenced systems with the previously mentioned modifications. The proposed method uses a Trie data structure, a precomputation on edit distance, and a smoothing technique. Bigram and trigram is tried along with Damerau-Levenshtein (DLD) and Levenshtein distance. Different sizes of data are also tried on Bigram and Trigram.

Table 5. Proposed System (Trie+DLD) Test Result Comparison for Bigram

Test Categories	1000 Data	2000 Data	3000 Data	4000 Data	5000 Data
Sentence Accuracy (%)	42	48	46	50	50
Word Accuracy (%)	80.77	82.69	84.62	85.58	84.62
False-Positive (%)	7.2	6.5	7.8	6.5	6.5
Time Spent (s)	0.8	1.8	0.8	0.9	1.0
Average Time Spent (ms)	15.1	36.8	15.3	17.4	18.9

Table 6. Proposed System (Trie+DLD) Test Result Comparison for Trigram

Test Categories	1000 Data	2000 Data	3000 Data	4000 Data	5000 Data
Sentence Accuracy (%)	6	8	10	12	16
Word Accuracy (%)	16.35	24.04	27.89	30.77	34.62
False-Positive (%)	0.94	0.94	0.94	0.94	0.94
Time Spent (s)	0.51	0.62	0.88	0.91	1.04
Average Time Spent (ms)	10.27	12.23	17.56	18.06	20.72

Based on the comparison of the test results of the proposed system for different sizes of data, the accuracy rate and the time spent increase as more data is used. The overall false-positive rate remains the same across all sizes of data. The main difference between bigram and trigram is that the test result for trigram is more consistent. In the test result for bigram, the accuracy falls from 85.58% to 84.62% when 5000 data is used. The newly added information (new word list, change in word frequency) affects the spelling correction result. Some of the previously correct words become incorrect and vice versa.

Table 7. Proposed System Test Results for Edit Distance Comparison

Test Categories	Bigram & Levenshtein	Trigram & Levenshtein	Bigram & Damerau-Levenshtein	Trigram & Damerau-Levenshtein
Sentence Accuracy (%)	36	10	50	16
Word Accuracy (%)	73.08	29.92	84.62	34.62
False-Positive (%)	6.54	0.94	6.54	0.94
Time Spent (s)	0.79	0.82	0.95	1.04
Average Time Spent (ms)	15.72	16.32	18.89	20.72

Based on the test result of proposed system for edit distance comparison, the accuracy of the system is improved at the cost of increased processing time. Using Damerau-Levenshtein distance yields a better result without significant change in processing time. The use of bigram or trigram also affects all aspects of the test. Overall, bigram has a higher accuracy, a higher false-positive rate and a lower processing time than those of trigram. The difference in accuracy shows that there is a high rate of data sparsity in trigram, and this is also proved by the previously mentioned perplexity test. The false-positive rate of trigram is higher than that of bigram. Naturally, a trigram contains a more contextual information than a bigram because of the difference in word pair length. While another reason for the low false-positive rate is because of the high rate of data sparsity which in turn lowers the amount of possible correction candidate.

4. Conclusion

The result of the research in creating a fast and accurate spelling correction system with the ability to fix real word error and non-word error ends with a moderately better result. Modifications made to the referenced system is able to increase its performance in term of accuracy and processing speed. The best result is achieved by the proposed system that uses a bigram with Damerau-Levenshtein distance with a sentence level accuracy of 50%, a word level accuracy of 84.62% and an average processing time per sentence of 18.89 ms.

Other things that can be mentioned based on the conducted research are as follows:

- The processing speed is increased significantly by using a Trie and precomputed edit distance.
- The use of a smoothing technique (Add-1 Laplace and Stupid Back-off) is able to reduce the high rate of data sparsity problem.
- The use of bigram yields a better result than using trigram, which is caused by the difference in rates of data sparsity.
- Using Damerau-Levenshtein distance yields a better result than using Levenshtein distance because it is able reach more variations of spelling errors, and the insignificant differences in processing time can be justified for the increase in accuracy.

Suggestions for further improvement in this research is to reduce memory usage of Trie data structure by compressing it and adding the use of database to store n-gram word list.

Another suggestions is the experiment on other smoothing technique to reduce data sparsity and improve the accuracy such as the Good Turing or Kneser-Ney smoothing. Another alternative is to use other data of different sources such as from the books.

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Fast and Accurate Spelling Correction Using Trie and Damerau-Levenshtein Distance Bigram

Viny Christanti M., Rudy Rudy, Dali S. Naga

Abstract

This research was intended to create a fast and accurate spelling correction system with the ability to handle both kind of spelling errors, non-word and real word errors. Existing spelling correction system was analyzed and was then applied some modifications to improve its accuracy and speed. The proposed spelling correction system is then built based on the method and intuition used by existing system along with the modifications made in previous step. The result is a various spelling correction system using different methods. Best result is achieved by the system that uses bigram with Trie and Damerau-Levenshtein distance with the word level accuracy of 84.62% and an average processing speed of 18.89 ms per sentence.

Keywords

damerau-levenshtein distance; bigram; spelling correction; trie;

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SJR

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Telkomnika



Country [Indonesia](#) - [SJR Ranking of Indonesia](#)

Subject [Engineering](#)
Area and [Electrical and Electronic Engineering](#)
Category

Publisher [Institute of Advanced Engineering and Science \(IAES\)](#)

Publication Journals

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Coverage 2011-2020

Scope TELKOMNIKA (Telecommunication Computing Electronics and Control) is a peer reviewed International Journal in English published four issues per year (March, June, September and December). The aim of TELKOMNIKA is to publish high-quality articles dedicated to all aspects of the latest outstanding developments in the field of electrical engineering. Its scope encompasses the engineering of signal processing, electrical (power), electronics, instrumentation & control, telecommunication, computing and informatics which covers, but not limited to, the following scope: Signal Processing[...] Electronics[...] Electrical[...] Telecommunication[...] Instrumentation & Control[...] Computing and Informatics[...]



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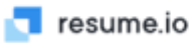
CV
Examples



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Builder



CV
Help & Tips



Quartiles

The set of journals have been ranked according to their SJR and divided into four equal groups, four quartiles. Q1 (green) comprises the quarter of the journals with the highest values, Q2 (yellow) the second highest values, Q3 (orange) the third highest values and Q4 (red) the lowest values.

Category	Year	Quartile
Electrical and Electronic Engineering	2012	Q3
Electrical and Electronic Engineering	2013	Q3
Electrical and Electronic Engineering	2014	Q3
Electrical and Electronic Engineering	2015	Q3
Electrical and Electronic Engineering	2016	Q3

SJR

The SJR is a size-independent prestige indicator that ranks journals by their 'average prestige per article'. It is based on the idea that 'all citations are not created equal'. SJR is a measure of scientific influence of journals that accounts for both the number of citations received by a journal and the importance or prestige of the journals where such citations come from. It measures the scientific influence of the average article in a journal, it expresses how central to the global scientific

discussion an average article of the journal is.

Year	SJR
2012	0.202
2013	0.232
2014	0.266

Citations per document

This indicator counts the number of citations received by documents from a journal and divides them by the total number of documents published in that journal. The chart shows the evolution of the average number of times documents published in a journal in the past two, three and four years have been cited in the current year. The two years line is equivalent to journal impact factor TM (Thomson Reuters) metric.

Cites per document	Year	Value
Cites / Doc. (4 years)	2011	0.000
Cites / Doc. (4 years)	2012	1.134
Cites / Doc. (4 years)	2013	0.716
Cites / Doc. (4 years)	2014	0.581
Cites / Doc. (4 years)	2015	0.558
Cites / Doc. (4 years)	2016	0.864
Cites / Doc. (4 years)	2017	0.694
Cites / Doc. (4 years)	2018	1.114
Cites / Doc. (4 years)	2019	0.864
Cites / Doc. (3 years)	2011	0.000
Cites / Doc. (3 years)	2012	1.134
Cites / Doc. (3 years)	2013	0.716
Cites / Doc. (3 years)	2014	0.581
Cites / Doc. (3 years)	2015	0.502
Cites / Doc. (3 years)	2016	0.830
Cites / Doc. (3 years)	2017	0.517

Total Cites Self-Cites

Evolution of the total number of citations and journal's self-citations received by a journal's published documents during the three previous years. Journal Self-citation is defined as the number of citation from a journal citing article to articles published by the same journal.

Cites	Year	Value
Self Cites	2011	0
Self Cites	2012	61
Self Cites	2013	60
Self Cites	2014	48

Self Cites 2015 71

■ External Cites per Doc ■ Cites per Doc

Evolution of the number of total citation per document and external citation per document (i.e. journal self-citations removed) received by a journal's published documents during the three previous years. External citations are calculated by subtracting the number of self-citations from the total number of citations received by the journal's documents.

Cites	Year	Value
External Cites per document	2011	0
External Cites per document	2012	0.224
External Cites per document	2013	0.346
External Cites per document	2014	0.468

■ % International Collaboration

International Collaboration accounts for the articles that have been produced by researchers from several countries. The chart shows the ratio of a journal's documents signed by researchers from more than one country; that is including more than one country address.

Year	International Collaboration
2011	20.29
2012	11.58
2013	7.77
2014	13.85
2015	18.54

■ Citable documents ■ Non-citable documents

Not every article in a journal is considered primary research and therefore "citable", this chart shows the ratio of a journal's articles including substantial research (research articles, conference papers and reviews) in three year windows vs. those documents other than research articles, reviews and conference papers.

Documents	Year	Value
Non-citable documents	2011	0
Non-citable documents	2012	2
Non-citable documents	2013	2
Non-citable documents	2014	2
Non-citable documents	2015	4

■ Cited documents ■ Uncited documents

Ratio of a journal's items, grouped in three years windows, that have been cited at least once vs. those not cited during the following year.

Documents	Year	Value
Uncited documents	2011	0
Uncited documents	2012	31
Uncited documents	2013	84
Uncited documents	2014	176
Uncited documents	2015	220
Uncited documents	2016	210



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abdelkbir 5 months ago

what is the Impact Factor for Telkomnika

reply



Melanie Ortiz 5 months ago

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Team

Dear Abdelkbir, thank you very much for your comment.
SCImago Journal and Country Rank uses Scopus data, our impact indicator is the SJR. Check out our web to localize the journal. We suggest you to consult the Journal Citation Report for other indicators (like Impact Factor) with a Web of Science data source. Best Regards, SCImago Team

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Siddhant Karmacharya 10 months ago

Hi, what is the word limit of this journal ?

reply



Melanie Ortiz 10 months ago

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Dear user,
thank you for contacting us.
Sorry to tell you that SCImago Journal & Country Rank is not a journal. SJR is a portal with scientometric indicators of journals indexed in Elsevier/Scopus.
Unfortunately, we cannot help you with your request, we suggest you to visit the journal's homepage or contact the journal's editorial staff , so they could inform you more deeply. You can see the updated journal's information just above .
Best Regards, SCImago Team

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mulyadi rusli 10 months ago

pardon me, can I know how long the reviewing process?

reply



Melanie Ortiz 10 months ago

SCImago
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Dear user,

thank you for contacting us.
Sorry to tell you that SCImago Journal & Country Rank is not a journal. SJR is a portal with scientometric indicators of journals indexed in Elsevier/Scopus.
Unfortunately, we cannot help you with your request, we suggest you to visit the journal's homepage or contact the journal's editorial staff , so they could inform you more deeply.
Best Regards, SCImago Team

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Muthna 1 year ago

I want answer, why Journal website appear error? how can check my research status? please inform?

reply



muthna 1 year ago

why journal website close? appear error page 404.

reply



Rajni Bhalla 2 years ago

Hello sir,
My paper suppose to publish in October. But still full text is not coming for this paper.As i have sent word file through mail also and uploaded on website also.Kindly let me know to whom should i contact.I have already

sent mail to editor number of times.Kindly do the needful.
Thanking you
Regards
Rajni

reply



Mohammed Al-obaidi 2 years ago

Hi, can I know how long the reviewing process?



Elena Corera 2 years ago

Dear Rajni,

thank you very much for your comment. Unfortunately, we cannot help you with your request, we suggest you contact journal's editorial staff so they could inform you more deeply. You can find contact information in SJR website <https://www.scimagojr.com>

Anyway, if there is any user who has already published in the journal, maybe could help us with your request.

Best Regards,
SCImago Team

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shahd 2 years ago

I want to Know how I can get the Impact Factor of any Journal

reply



Elena Corera 2 years ago

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Team

Dear Ahahd,

thank you very much for your request. You can consult that information in SJR website.

Best Regards,
SCImago Team

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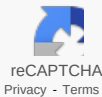
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