



POLİTEKNİK DERGİSİ

JOURNAL of POLYTECHNIC

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)

URL: <http://dergipark.gov.tr/politeknik>



Radio frequency transient segment detection based on akaike information criterion

Akaike bilgi kriteri ile radyo frekans geçici hal segment tespiti

Yazar(lar) (Author(s)): Saleh Abulgasem AJOUAT¹, Necmi Serkan TEZEL²

ORCID¹: 0000-0003-3743-0920

ORCID²: 0000-0002-9452-677X

Bu makaleye şu şekilde atıfta bulunabilirsiniz (To cite to this article): AJOUAT S. A., TEZEL N. S., "Radio frequency transient segment detection based on akaike information criterion", *Politeknik Dergisi*, 25(4): 1681-1686, (2022).

Erişim linki (To link to this article): <http://dergipark.gov.tr/politeknik/archive>

DOI: 10.2339/politeknik.967341

Radio Frequency Transient Segment Detection Based on Akaike Information Criterion

Highlights

- ❖ To automatic catch the start point of Bluetooth signal
- ❖ Avoid processing interfering noise and start with sender's signal
- ❖ Find out to what extent can the algorithm work with increasing noise
- ❖ Illustrate the feasibility of method by applying huge amount of data

Graphical Abstract

Akaike Information Criterion AIC algorithm is applied on Bluetooth signal to capture the start point of transient segment by finding the global minimum of AIC function as illustrated in three main process in this block diagram

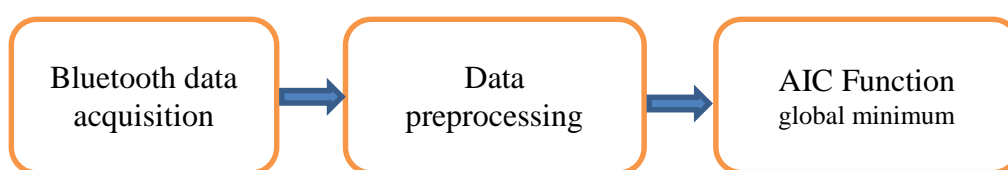


Figure. Block Diagram of Proposed Method

Aim

The automatic detection of actual signal is essential issue in many fields especially in Radio Frequency communications, the optimum process leads to interpret RF data efficiently and quickly for any purposes and avoid handling redundant information like background noise. The proposed method Akaike Information Criterion AIC is presented to overcome the issues and detect the actual signal of particular transmitter.

Design & Methodology

Detection algorithm under name of Akaike Information Criterion that can be calculated immediately from the time series has been implemented in MATLAB environment. The sudden change point of examined record is the lowest value of the AIC function. In all tested records there is always one global minimum discriminates the noise from arisen signal

Originality

In this paper, in order to measure the performance of the proposed method; Bluetooth signals are obtained from different cell phones and stored as plain text format to passed into Akaike Information Criterion AIC which built as Matlab function. Detection transient of Bluetooth signal by AIC has not done before.

Findings

The proposed method is effective, fast and reliable in presence of relatively high amplitude noise

Conclusion

The proposed method based on Akaike Information Criterion algorithm has a capability to detect the start of transient segment of Bluetooth signal directly and also in case of baseband down-conversion and Empirical Mode Decomposition with tradeoff between precision and time consuming.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Akaike Bilgi Kriteri ile Radyo Frekans Geçici Hal Segment Tespiti

Araştırma Makalesi / Research Article

Saleh Abulgasem AJOUAT^{1*}, Necmi Serkan TEZEL²

Department of Electrical and Electronics Engineering, Karabuk University, Turkey

(Geliş/Received : 09.07.2021 ; Kabul/Accepted : 10.08.2021 ; Erken Görünüm/Early View : 23.08.2021)

ÖZ

RF verilerinin doğru olarak değerlendirilmesi, göndericinin açık olduğu zamanın tam olarak algılanmasından veya bilinmesinden başlar, bu zorluk iki önemli konuyu içerir; kaçınılmaz arka plan gürültüsü gibi gereksiz bilgileri işlemeyi önlemek ki bu işlemi hızlandır ve diğer konu, o gönderenin tam davranışını incelemektir. Bu çalışmada, Akaike Bilgi Kriterini (AIC) kullanılarak Bluetooth sinyalinin geçici olarak başlangıcını otomatik olarak yakalamak için bir yöntem geliştirilmiştir. Önerilen yöntem, en yaygın cep telefonu markalarından farklı yollarla alınan gerçek veriler üzerinde sinyal-gürültü oranının değişimi ile incelenmiştir. AIC algoritması, yüksek genlikli rastgele bir gürültüden etkilenmediğini göstermiştir.

Anahtar Kelimeler: Akaike bilgi kriteri, geçici durum algılama, bluetooth sinyali.

Radio Frequency Transient Segment Detection Based on Akaike Information Criterion

ABSTRACT

The precise interpreting of RF data starts from retrieving or knowing the exact time instant at which moment the sender is turned on, this challenge implies two important issues; prevent manipulating redundant information such as unavoidable background noise which speed up the processing and the other issue is to study the exact behavior of that sender. A method has been developed to automatically catch the onset in transient of Bluetooth signal using of the Akaike Information Criterion (AIC). Present method has been examined on real world data taken from the most common cellular phones brands by different ways with variation of signal to noise ratio. The AIC algorithm shows robustness in the existence of relatively a high-amplitude random noise.

Keywords: Akaike information criterion, transient detection, bluetooth signal.

INTRODUCTION

Accurate detection and picking up in RF data whether is transient or steady state is crucial for many applications. A study suggested a Specific Emitter Identification as a method to achieve transient fingerprint characteristics of obtained energy envelope of transient signals [1]. This research introduces a new algorithm that employs the phase features for detection determinations [2]. Other research offered a method for radio transmitter identification that used frequency domain feature of steady state signal [3].

Perceptibly the most important features of Bluetooth signal Figure 1 are not settled in the noise part also the time duration of this redundant segment varies unexpectedly Figure 2. So that the first process of any application procedure is to ensure that the noise is eliminated from the manipulating followed by knowing the start and the end of each segment automatically, so they can be studied separately. However, knowing the end of transient segment is not as important as start point; where it is sufficient to count on fixed length of transient segment [4].

Since the detection of change point plays an important aspect in many fields like enhance the security by defining RF fingerprints [5], so that it should be clarified properly in order to create precise RF fingerprints. In doing so; there are many methods can be used like use of energy envelope of signals which is quite popular approach for transients time picking [6]. Another sort of indicator that uses energy of time window chunks and the matching zero crossings of that signal with adaptive threshold was also presented [7]. Some methods such as the threshold, and Bayesian Step Change Detector approaches were introduced to detect change point [8], [9]. A method depends on energy criteria have been newly proposed as an approach to catch the onset time of transient [10].

DATA COLLECTION AND PREPARATION

The Bluetooth waveforms data has been obtained from [11]. The signals have been acquired at good condition of humanity and temperature with the following sampling rates: 5 GHz, 10 GHz, and 20 GHz. The sampling rate has direct effect on the recorded signal; where there is always need to represent signals by high sampling rate, it is a kind of assurance to watch the exact behavior of certain transmitter also as an example the

*Sorumlu Yazar (Corresponding Author)
e-posta : saleh.abulgasem@gmail.com

fingerprint consists of some features, that may pulled out from the characteristics of the signal. In case of ignoring the sampling rate, the information may get lost. Consequently, the yielded fingerprint of that sender would not denote the real features of the produced signal. The lowest limit of sampling rate has been declared by Nyquist theorem, in case of Bluetooth signal the carrier frequency in range [2.4-2.483 GHz] so it needs a digitizer that has around 5 GHz sampling frequency at least.

A data retrieval system was structured to record the Bluetooth signals in range 2.4-2.48 GHz ISM band with three main sampling rates [11], as illustrated in Figure 3.

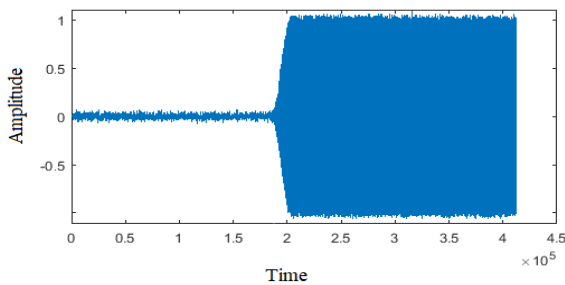


Figure 1 A sample of Bluetooth Signal one record

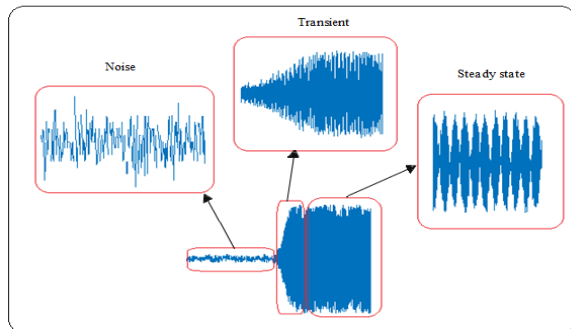


Figure 2 Bluetooth Signal Segments

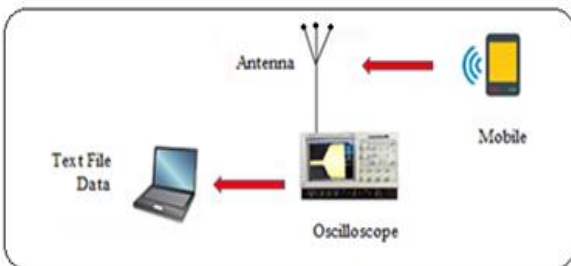


Figure 3 Bluetooth Data Collection Structure

Since the collected signals have unrelated amplitudes, normalization is preferred to keep all the max values of the signals between [+1 -1] which is much better from processing prospective. The filtration process is also needed to get rid of unwanted components and to make the signal smoother. A sample of filtered normalized studied signal of selected cellular phone is seen in Figure 1.

TRANSIENT DETECTION TECHNIQUE

Most of produced signals come with unavoided noise with different time lengths and amplitudes as a result of

electronic components, which enforce the researchers to find an automatic way to deal properly with them and get rid of undesired components. A new method is presented and applied on more than 10000 records of most popular cellular phones named (Samsung, Huawei, iPhone, LG, Sony, and Xiaomi) to reveal the correct time instant of onset point of Bluetooth signal.

PROPOSED METHOD

Akaike Information Criteria AIC

Akaike’s information criterion AIC was created in 1971 [12]. AIC detector is an algorithm whose equivalent value can be determined for each sample along the studied signal. The estimated global minimum of AIC provides the best splitting of that signal and this is the characteristic of AIC detector which is typically taken an advantage by different methods in multiple applications. Regarding AIC computations there are two methods used with Auto-Regressive coefficients and without them. For typical Auto-Regressive AIC (AR-AIC) method, the studied signal is separated into locally stationary sections, each one is handled as an AR process and the chunks before and after the change point time are two unlike stationary processes, the order of AR process is then defined by AIC function [13].

The second approach of computing the AIC function which adapted here is done without using AR coefficients, which can be calculated directly from the time series. The turn on change point is again the minimum of the AIC function. For Bluetooth record x of total samples N, the AIC_{min} sample is recovered by [14]:

$$AIC(k) = k \times \log(\text{var}(x(1, k))) + (N - k - 1) \times (\log(\text{var}(x(1 + k, N)))) \tag{1}$$

Where; k is movement step all over the samples. The AIC detector specifies the weak-up point as the global minimum of whole signal. In this study, downsampling is needed which lessen the sample rate by factor n then the formula (1) is regarded for figuring AIC function. Actually, the AIC function can handle and perform detection without involving downsampling but depends on available facilities, AIC algorithm will take long time, for instance the time required to manipulate one record 5 GHz is around 9 sec while with aid of downsampling is 0.04 sec with the same result.

The change point or transient segment is detected from the transmitted signal via the following steps based on AIC algorithm:

1. The Bluetooth record should be normalized, and centered.
2. The processed record is down-converted to baseband using designed Low pass filter.
3. Down-sampling factor d is required as a key role for speeding up the whole process

4. The produced signal is conveyed into AIC function without pre-defining threshold value.
5. The global minimum on the AIC is found, and then the matched time sample is clarified times by downsampling factor n.

AIC ALGORITHM APPLIED TO BLUETOOTH RECORDS DATASET

Data from smartphones have been recorded in laboratory by high rate oscilloscope with adequate distance and isolated from interference of other devices [11].

The first step of proposed method is downsampling processed signal by a factor n, however this step is only needed at high sampling rate. Downsampling is defined as process of discarding or throwing samples by factor n in order to reduce the sampling rate without using low pass filter which is the case of decimation process, and in case of violating or misrepresenting factor n will reflect on detected onset point. Equation 1 was considered to compute the AIC global minimum shown on Figure 4. The recorded signals have been treated by different way. First way the records directly passed into AIC algorithm without any preprocessing with background noise as they are produced from their equipment. Second way the modulated records are down-converted into baseband. The third way the records are decomposed into mono-components by Empirical Mode Decomposition EMD.

EMD treats the non-stationary signal and breaks down a multi-component signal to generate unique mono-component called Intrinsic Mode Function IMF in time domain. All produced IMFs are achieved from applying sifting process [15] to the rest of multi-component signal. The non-stationary original signal can be reassembled as the summation of all produced IMFs.

As depicted in Figure 4, with chosen down-sampling factor the moving step k value is multiplied by the log of

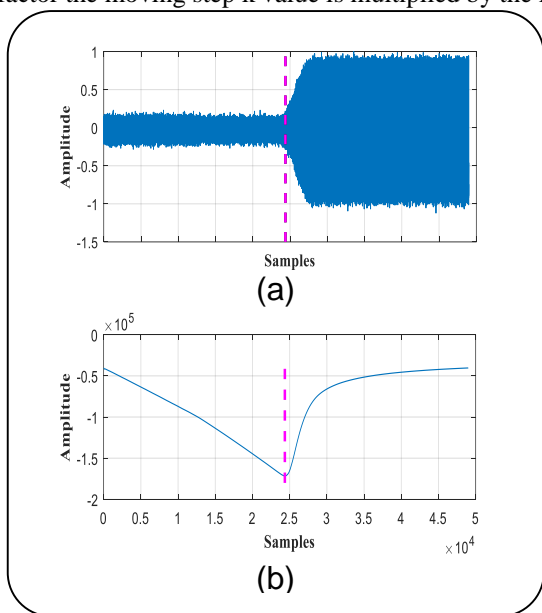


Figure 4 (a) The selected recorded signal, and (b) is the equivalent AIC values

the variance from sample 1 to k. The variance of segment at the beginning of time series is getting smaller. Then the value is going to drop as k rises. At the abrupt change point, the calculated term starts to reverse direction and upturns in amplitude. This AIC minimum is selected as the weak up point. For a selected record the change point is visible, and AIC algorithm is very fast having a very distinct global minimum.

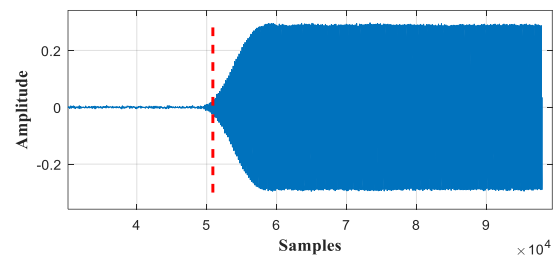


Figure 5 The dotted red line k bounds two neighboring time series with altered features. Background noise is discriminated from 1 to k, and arisen signal is recognized from k+1 to N.

For the same examined record with process of down-conversion the AIC splitter is more precisely with relatively more consuming time Figure 5.

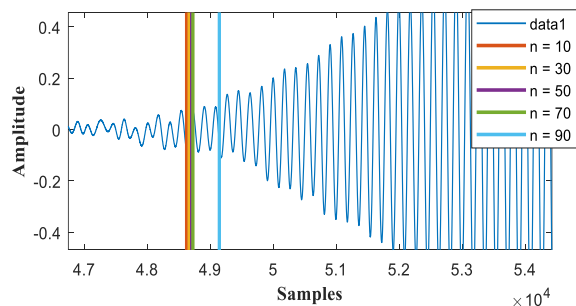


Figure 6 Down-sampling Factor Effect

The effect of down-sampling factor n on a particular record is presented in Figure 6, having no drawbacks on any other process; it is clear that at small range the splitter line will not be affected but at higher value of n will give imprecise splitting point, and incorrect onset point with overvalued factor n. In this study, all downsampling factors have been set experimentally.

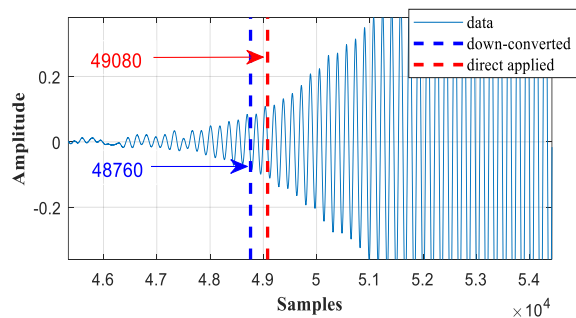


Figure 7 AIC_{min} of cases down-converted signal and direct applied

Suppose a signal of total length ‘N’ can be divided into stationary components. As distinct here, a stationary process has fixed component over the time of the testing. By visualizing or by selecting criteria the 1st IMF is the dominant and chosen to be passed into AIC algorithm.

At global minimum the algorithm is distinguishing that the first chunk is noise and the second chunk is sender behavior over two intervals as stated in Figure 7, the figure shows the onset point of two used methods with slightly difference in precision. In case of the three mentioned methods the splitter lines usually take place by this order in clean signal see Figure 8.

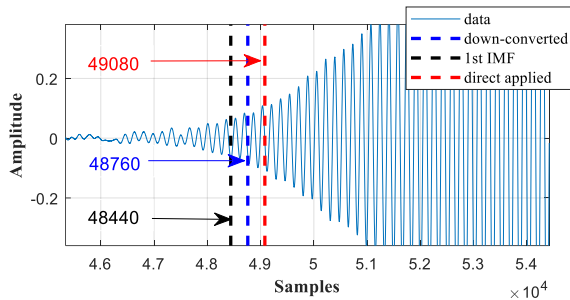


Figure 8 AIC_{min} of 1st IMF signal, down-converted, and direct applied

SNR PERFORMANCE

In general the definition of Signal to Noise Ratio is based on following expression:

$$SNR_P = 10 \log_{10} \left(\frac{A_{noisy}}{A_{noise}} - 1 \right) \tag{2}$$

In particular SNR is considered as the ratio of the mean absolute value after (i.e. noisy signal) and before (i.e. noise) change point sample. To achieve variety of SNR values, the studied signals are handled by different ways, this is done by taking noise that artificially created then added to the clean signal and amplified by factor to that unseen level for the AIC algorithm. The AIC min found before adding any noise is considered as a reference splitting point to find the error when the noise is applied as expressed in this equation:

$$Error = (P_r - P) / f_s \text{ sec} \tag{3}$$

Where; P_r is the onset point found before adding noise which regarded as reference point, P is the onset point found after adding noise, and f_s is the frequency sampling.

The exact same noise that produced from a particular record is passed into AIC function in three mentioned ways:

- Direct applied of the original signal
- Down-converted signal, and
- The first IMF produced by EMD

The SNR has been chosen to reflect the capability of AIC algorithm to catch the sudden change when the signal gets distorted:

$$SNR_{MAV} = 20 \log_{10} \left(\frac{N_2 \sum_1^k |x|}{N_1 \sum_k^N |x|} \right) \tag{4}$$

Where; N₁ is length of signal from 1 to k, and N₂ length from k to the N

Because the original record is having background noise many of the AIC minimum values lay in unseen region where the onset point cannot be detected correctly, with increasing factor d the error obtained from equation 3 is corrected, see Figure 9 and Figure 10, and in the other case of down-converted signal most of AIC values are standing in seen region where the algorithm can discriminate between two series despite the signal is getting distortion. An example of SNR levels of original signal is depicted in Figure 13, these distortion levels are plotted at d=45, and 100, this is done by creating random noise and then specify the SNR levels by one of the equations; 2, or 4. The best value of SNR regarding equation 4 that can be achieved from manipulated signal is shown in Figure 9, and equivalent error is illustrated in Figure 10, and Figure 12, for instance the best SNR level of down-converted signal is 30 dB.

At low SNR, there are always one global minimum and the algorithm still gives accurately splitting point. If the level of SNR is too low, sudden change point is unseen and will be shifted into any direction depending on waveform distortion. Figure 11 shows the down-converted signal with all AIC minimum values that achieved after altering factor d. As the signal gets distorted the algorithm starts giving imprecise onset points Figure 11 (middle of figure). Wrong onset point of processed signal yielded by the algorithm is referred as unseen onset, as depicted in Figure 11 (right side of figure).

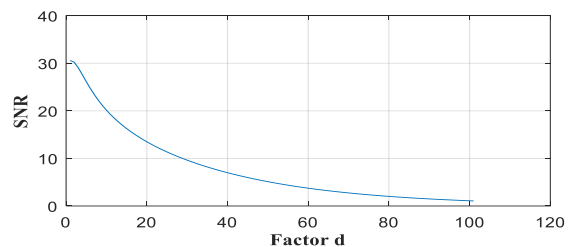


Figure 9 SNR Levels of Down-converted Signal

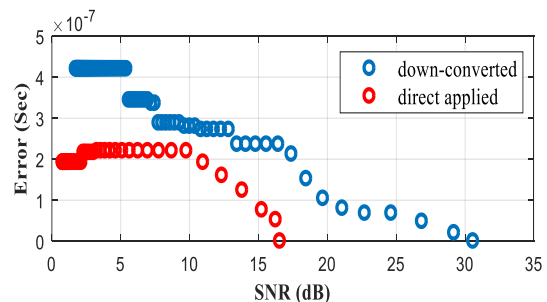


Figure 10 SNR Performance of down-converted and direct applied algorithm cases

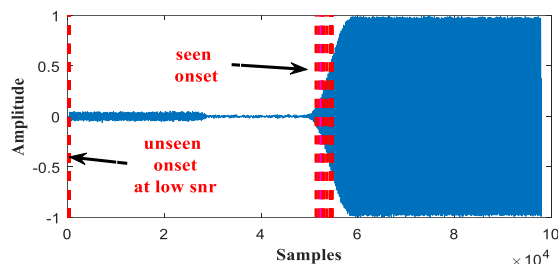


Figure 11 Down-converted Signal with AICmin of all SNR Levels

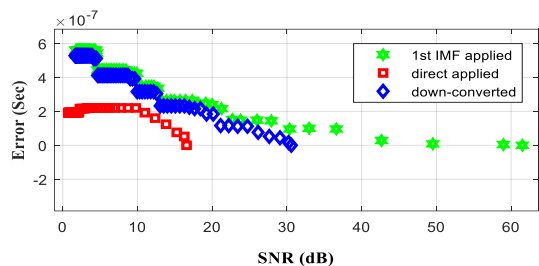


Figure 12 SNR Performance for 1st IMF, down-converted and direct applied cases

Retrieving results from applying the original signal directly without any sorts of preprocessing into the algorithm is an advantage of this method, also the average consuming time is around 0.03 sec. The performance of the algorithm is effective and good as long as the amplitude of interfered noise is less than the amplitude of sender signal where the algorithm is not affected by just few high amplitude spikes at the beginning of examined signal.

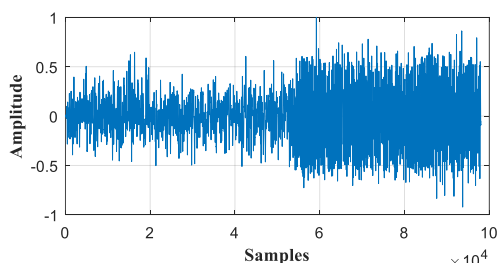


Figure 13 (a) Distorted Signal at Selected Level (d=45)

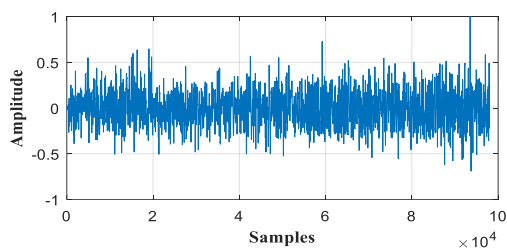


Figure 13 (b) Distorted Signal at Selected Level (d=100)

ACKNOWLEDGEMENT

It has been successfully completed as a thesis study at Karabuk University, Graduate School of Natural And Applied Sciences, Department of Electrical & Electronics Engineering.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Saleh AJOUAT: Performed the experiments and analyse the results.

Necmi Serkan TEZEL: Wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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