HUMAN GESTURE RECOGNITION USING BISPECTRUM-BASED WIRELESS SIGNAL PROCESSING

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Recently, state-of-the-art technologies are attracting considerable attention and developing successfully for human gesture detection, recognition and classification by using wireless signals. By using different hand motion in-air, a user could provide remote control of smart home devices or car multimedia systems. Systems operating without any physical contact between human and different devices can be also useful for interface with computers exploiting of human gestures, gaming, outdoor lighting, remote controlling the UAV/multicopters, security applications, industrial robotics, health (vital sensing) and others. In these systems, detection, recognition and classification procedures are performed by extraction the contributions in the electromagnetic field caused by human gesture impact. In this paper, novel bispectrum-based strategy is proposed and experimentally studied for human gesture classification. Novel type of classification features extracted from signal distorted by *human gestures is suggested by evaluation the third-order spectrum named bispectrum. It has been demonstrated that phase bispectrum or biphase contains unique discriminative features serving for detection and classification of human gestures. The feasibility of developed hardware and software is demonstrated experimentally. It is shown that suggested bispectrum-based strategy provides invariance property to random signal time delays and considerable signal magnitude variations usually observed in the intricate indoor multi-path interference environment. Human gesture classification accuracy has been evaluated and discussed. Our results indicate robustness of bispectrum-based information features for human gesture recognition and classification in complicated indoor interference environment.*

KEY WORDS: *human gesture classification system, Wi-Fi signals, higher-order spectral analysis, phase coupling, bispectrum, biamplitude, biphase, bicoherence*

1. INTRODUCTION

Recently, intensive investigations are performed for development a human gesture recognition and classification systems using wireless signals commonly exploited in the Wi-Fi and FM devices, in the wireless communications, as well as in the television [1] – [4]. Obtained nowadays-experimental results demonstrate the possibility of remote control the electronic devices by a certain movements of the human hands that distort wireless signal parameters. In particular, a user can be located behind the wall and remotely control consumer electronics devices situated at indoor environment [5].

Human gesture detection, recognition and classification systems serve as the promising tools in the wide variety of applications like: automation of control of household appliances, in so called "smart house"; development of a new type of contactless computer interface by virtual touch screens; human interaction with robot; multimedia car devices contactless controlled by car driver; monitoring of young infants; security service such as intruder detection system contained the motion sensors; care the elderly and disabled persons; computer gaming; and others. The latter systems operate by using evaluation of the signal envelope variations and Doppler frequency shifts provoked by human hands moving in the electromagnetic field irradiated by Wi-Fi or radio FM devices.

In the real life, human gesture recognition and classification systems operate under intricate interference environment. Accuracy of human gesture classification largely depends on considerable dynamic variations of radio signal magnitude that provoke corresponding variations of signal-to-noise ratio (SNR) variations. In addition, dependence on the human hand velocity and location of human relatively receiving sensors cause certain limitation in the interference immunity and gesture classification probability. In addition, Doppler spectral content of the wireless signal influenced by human gesture can vary considerably for the human gestures of the same kinds.

Over the last few decades, higher-order spectral analysis (HOSA) has been effectively used for investigation of different signals in order to extract non-linear and non-Gaussian contributions contained in raw processed data. One of the most widespread HOSA approaches is the third-order spectral analysis or bispectral analysis

[6], [7]. Bispectrum-based strategy can serve as a promising tool for detection and extraction the data that contained information about interactions between spectral components and phase coupling. The benefits provided by bispectrum-based strategy are the following: possibility of extracting phase coupled contributions contained in the signal, high noise resistance to additive Gaussian noise, as well as invariance to the random signal delays [6], [7]. Invariance property of bispectrum to random signal delays provides a possibility for coherent accumulation and averaging of weak noisy bispectral estimates in order to smooth noise contributions.

In this paper, we propose a new technique that will effectively recognize and classify the gestures of a person, and which will be invariant to the variations of amplitude and rate of the human gestures.

The rest of the paper is organized as follows. Section 2 presents short description of basic bispectrum properties. Section 3 describes the algorithm designed for human gesture recognition and classification. Section 4 presents the experimental results obtained for classifying different human gestures types in real time, and Section 5 concludes the paper.

2. BASIC PROPERTIES OF BISPECTRUM

Extracting useful information from observed raw data is frequently restricted by influence of interference. In this paper, we propose exploiting the properties of bispectrum to derive human gesture classification features contained in the radio signals distorted by human gestures under influence of interference.

Proposed in this paper approach is based on detecting, recognition and classification of human gestures by extraction information features contained in the wireless signal bispectrum. Three-dimensional complex-valued bispectrum $B_x(p,q)$ can be computed by two-dimensional Fourier transform of triple autocorrelation function $R_x(k, l)$ [7]. For some observed time series x(i), the functions $B_x(p, q)$ and $R_x(k, l)$ can be written in the following forms, respectively

$$\dot{B}_x(p,ql) = \sum_{k=-I+1}^{I-1} \sum_{l=-I+1}^{I-1} R_x(k,l) \exp[-j2\pi(kp+lq)] = \left|\dot{B}_x(p,ql)\right| e^{j\gamma_x(p,q)} , \qquad (1)$$

$$R_x(k,l) = \left\langle \sum_{i=0}^{I-1} [x^{(m)}(i) - E][x^{(m)}(i+k) - E][x^{(m)}(i+l) - E] \right\rangle_{M\to\infty} , \qquad (2)$$

where p, q and i, k, l are the frequency and temporal indexes, respectively; $|B_x(p, q)|$ and $\gamma_x(p, q)$ are the amplitude bispectrum (biamplitude) and phase bispectrum (biphase), respectively; $<\ldots>_M$ denotes ensemble averaging procedure performed by M observed realizations; E is the mean value of a process x(i) under study.

Biphase $\gamma_x(p,q)$ in (2) can be written in the following form

$$\gamma_x(p,q) = a\tan\left(\frac{\mathrm{Im}(\dot{B}_x(p,q))}{\mathrm{Re}(\dot{B}_x(p,q))}\right) . \qquad (3)$$

Received radio signal modulated by human gestures contains some mixture of useful information data and interference contributions. The interference contributions can comprise additive Gaussian noise; random time delays of radio signals usually caused by multi-path propagation of radio waves at indoor environment; and random, often non-stationary signal amplitude variations.

Common restrictions of the approaches developed for human gesture detection, recognition and classification by using Wi-Fi and FM radio signals [1] – [4] is in impossibility to retrieve important information in the form of phase coupling contributions contained in the processed signals. Phase coupling can serve as additional discriminative feature for recognition individual human gestures. Therefore, suggested bispectrum-based strategy can provide extracting a novel discriminative and classification features contained unique phase coupling contributions provoked by human gestures.

It is well-known, that for additive zero-mean Gaussian noise bispectrum tends to zero value [7]. By using this property, one can provide suppression and decreasing the noise contribution emphasizing at the same time human gesture contributions. Therefore, bispectrum-based strategy can provide increasing the SNR value and enhance noise immunity performance in human gesture classification system.

3. HUMAN GESTURE RECOGNITION AND CLASSIFICATION BY BISPECTRUM-BASED DATA PROCESSING

First, we describe suggested technique developed for human gesture recognition and classification and operating in the high frequency radiation field environment like Wi-Fi radiation, for instance. Proposed technique contains the data processing steps listed below.

1. Measurements of the envelope parameters contained in the high frequency carrier and caused by human gesture impact. In order to smooth additive noise, averaging filtering procedure is exploited. As a result, the envelope component serving for extraction of human gesture contribution is formed at the averaging filter output.

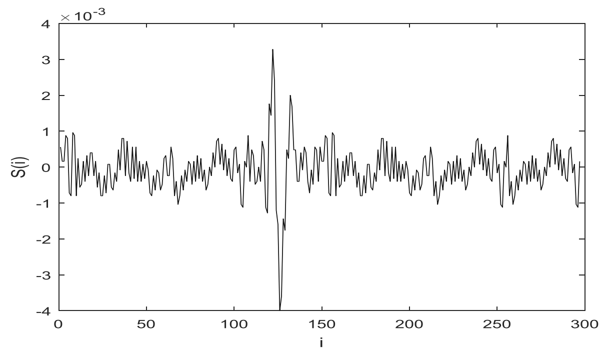
At this data processing step, the envelope component is read and its waveform is recorded and accumulated in the memory. The data reading procedure is organized in the suggested experimental layout by amplitude detector circuit and DS1052E digital oscilloscope.

One example of the experimental extraction of the envelope component contaminated by noise is illustrated in Fig. 1a. Signal at the averaging filter output is represented in Fig. 1b.

2. Depending on human gesture velocity, total number of the samples contained in the digitized received signal can considerably vary increasing with gesture speed. In order to provide invariance property relatively to the human gesture speed variations, heterodyning procedure is proposed. Heterodyning procedure provides signal spectrum transform from one high frequency range to another low frequency range. As a result, signal reconstructed from Fourier spectrum and computed after heterodyning will have forever the fixed number of the samples regardless from human gesture speed. Experimental results of heterodyning procedure performed for the signal envelope component is demonstrated in Fig. 2a – d.

3. Our strategy proposed for human gesture recognition and classification is based on the extraction of the information features contained in the bispectrum. For

this purpose, bimagnitude and biphase estimates are computed for extraction information features. One experimental example of bimagnitude signature computed for an arbitrary human gesture is represented in Fig. 3.



a)

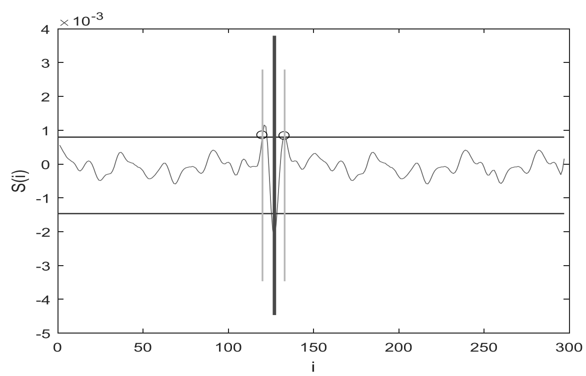


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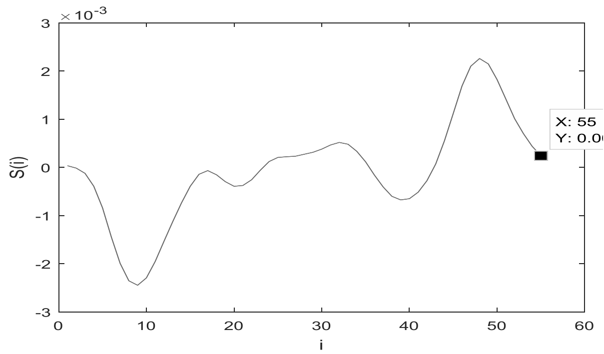
FIG. 1: Experimental example of the signal envelope component contaminated by noise (a). Result of filtering and localization of the human gesture contribution (b)



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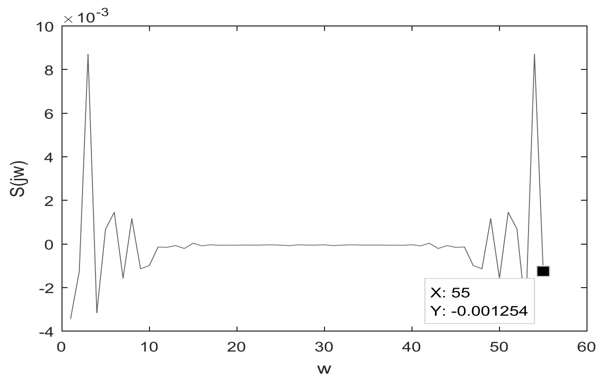

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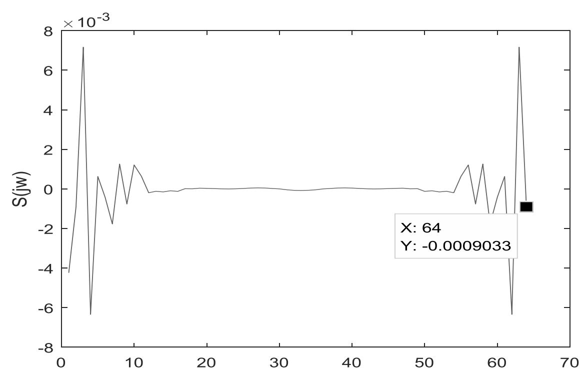

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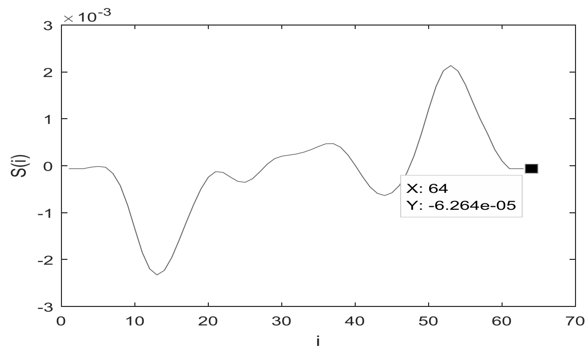


d)

FIG. 2: The stages of the heterodyning procedure: a) signal segment contained initial human gesture contribution; b) amplitude Fourier spectrum corresponding to the initial human gesture; c) Fourier spectrum after heterodyning; d) signal reconstructed after heterodyning

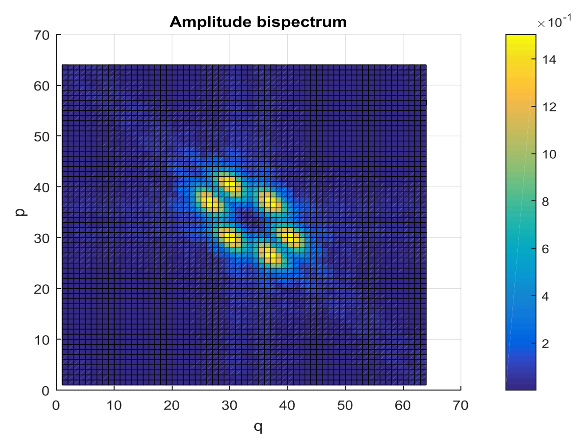


FIG. 3: Amplitude bispectrum (biamplitude)

4. Evaluation of phase bispectrum (biphase) and bicoherence gives unique opportunity for obtaining invariance depiction of human gesture contribution contained in the signal envelope shape variations and provoked by human gesture impact.

Biphase distribution can be obtained from complex-valued bispectrum estimate by computations performed according to the formula (3).

One experimental example of biphase signature contained human gesture contribution and computed after above mentioned heterodyning procedure is demonstrated in Fig. 4.

Bicoherence value provides extraction the information about phase relationships existing between Fourier-spectrum components and caused by non-linear effects. Information about phase coupling may be evaluated by estimation the bicoherence value. According to the definitions given in [7], dual frequency and real-valued bicoherence function b(p, q) can be written as follows

$$b(p,q) = \frac{|B(p,q)|^2}{P(p)P(q)P(p+q)}, \qquad (4)$$

where P(p) is the spectral power density.

Experimental example of bicoherence signature contained human gesture contributions and computed according to (4) is shown in Fig. 4.

5. Human gesture classification feature providing invariance property is proposed to be evaluated in the form of parameter $P(\alpha)$ as

$$P(\alpha) = a\tan\left[\frac{I_i(\alpha)}{I_r(\alpha)}\right], \qquad -\frac{\pi}{2} < P(\alpha) \le \frac{\pi}{2}, \qquad (5)$$

where $I_r(\alpha) + jI_i(\alpha) = \sum_{p=1}^{(N/2-1)/(1+\alpha)} B(p,\alpha p)$; $0 < \alpha < 1$; $B(p,\alpha p)$ is the biamplitude samples located along a radial slice with the slope equal to α given in the bifrequency plane (p, q).

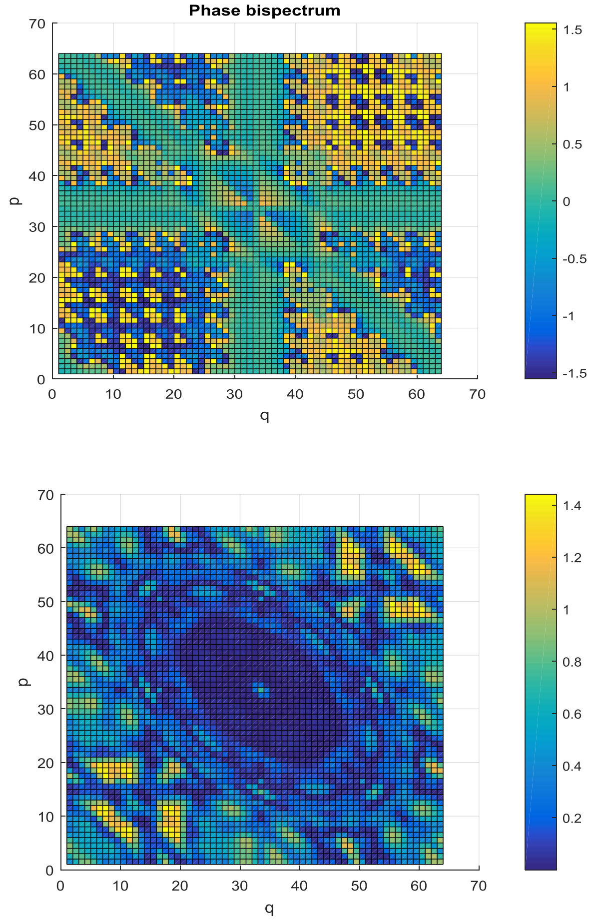


FIG. **4**: Biphase (upper signature) and bicoherence (lower signature) computed for the hand human gesture "Left to Right" type

In Fig. 5, black triangle indicates common main bispectral triangular domain and red color specifies radial slice location noted in expression (5).

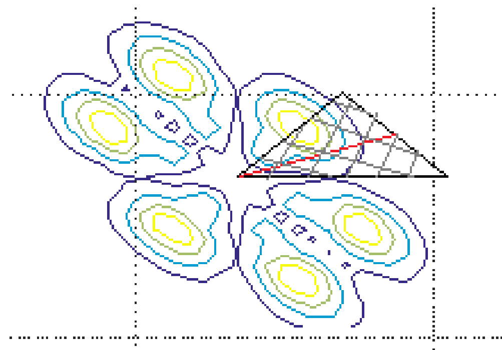


FIG. 5: The main triangular domain and radial slice marked by black and red color, respectively

6. Initial test data are necessary for examination of human gesture classification performance. For this purpose, four test matrices of biphase values, four bicoherence matrixes, and four P(α) values contained human gesture classification features were initially computed and recorded.

Test initial P(α) values were computed as follows: for human gesture "Top-Down", P(α) = 0.11; for human gesture, "Bottom-Up" P(α) = 1.03; for human gesture, "Left to Right" P(α) = – 0.4; for human gesture, "Right to Left" P(α) = 0.04.

7. In order to make decision in favor of one or the other human gesture type, the comparison is carried out between the initial values P(α) computed for four human gesture types in accordance to (5) and the value P(α) extracted from biamplitude signature computed for experimentally measured signal. If the difference between the measured and one of four initial values is minimal, decision will be made in the benefit of corresponding human gesture type. Maximal difference between the mentioned

values means that experimentally measured human gesture type is of 100% unlikely to be true. The latter human gesture type does not participate in further data processing.

At the second stage of human gesture classification, additional classification feature are evaluated in the form of biphase values.

First, biphase signature matrix is computed for experimentally measured data.

Second, experimental biphase matrix is compared with initial matrices computed according to the formula (3) for each type of studied human gestures. In order to make decision in the benefit of current human gesture type, the comparison of the correlation coefficients is carried out. Correlation coefficients are computed in the following form

$$Rxy_{\%} = \frac{1}{n}\sum_{j=1}^{n} \frac{\sum_{i=1}^{t}(x_{j,i} - \bar{x}_j)(y_{j,i} - \bar{y}_j)}{\sqrt{\sum_{i=1}^{t}(x_{j,i} - \bar{x}_j)^2}\sqrt{\sum_{i=1}^{t}(y_{j,i} - \bar{y}_j)^2}} \times 100\% \quad , \tag{6}$$

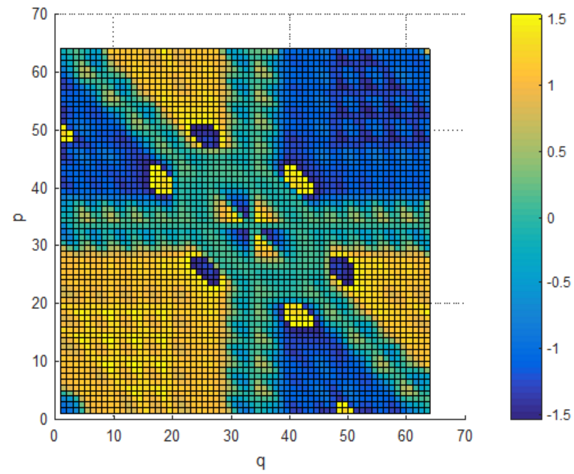
where by x and y are denoted the matrix elements corresponding to the measured biphase signature and initial biphase signature, respectively.

Third, maximum value of the correlation coefficient (6) indicates decision made in the favor of current human gesture type

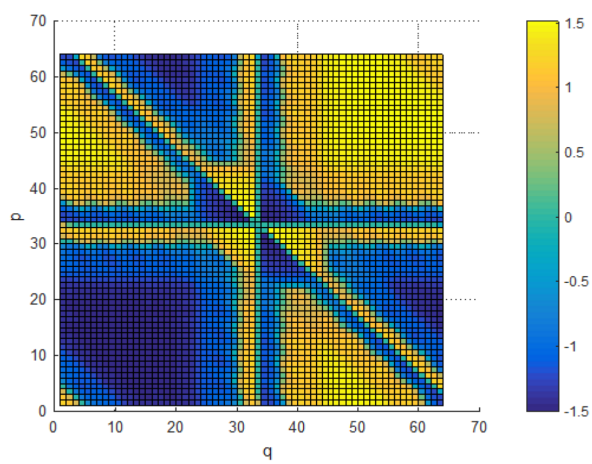
In the fourth number of classification stage, the results of the first to the third stage are compared, during which the type of the current human gesture is classified.

Three examples of initial biphase signatures corresponding to three types of "Top-Down", "Bottom-Up", and "Left to Right" human gestures are shown in Fig. 6.

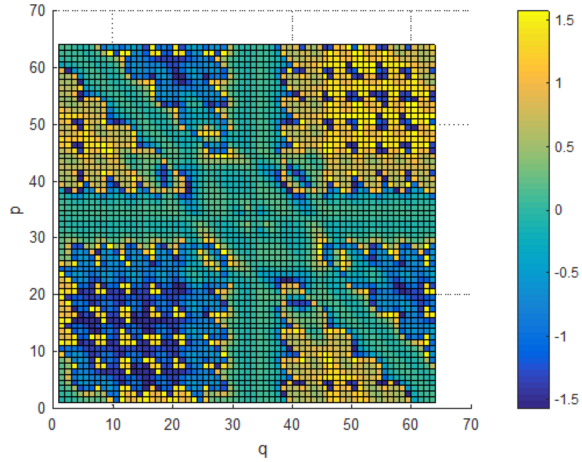
Three different examples of initial bicoherence signatures computed according to the formula (4) and corresponding to three types of "Top-Down", "Bottom-Up", and "Left to Right" human gestures are demonstrated in Fig. 7.



(a)

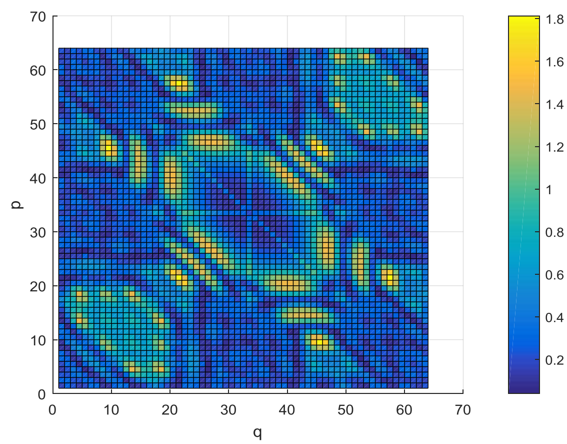


(b)

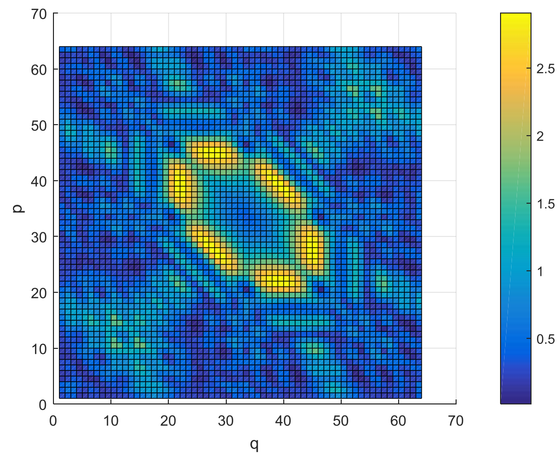


(c)

FIG. 6: Initial biphase signatures: (a) "Top-Down"; (b) "Bottom-Up"; (c) "Left to Right" human gestures



(a)



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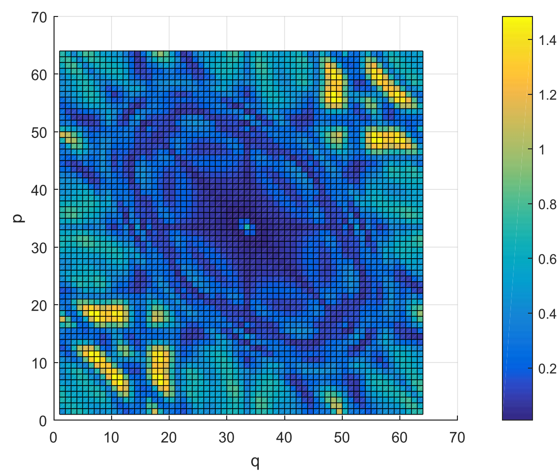

(c)

FIG. 7: Initial bicoherence signatures: (a) "Top-Down"; (b) "Bottom-Up"; (c) "Left to Right" human gestures

4. DISCUSSION OF EXPERIMENTAL RESULTS

The probability of correct and false human gesture recognition and classification evaluated by suggested bispectrum-based strategy is demonstrated in Table 1.

It is seen from Table 1 that the averaged probability corresponding to correct human gesture recognition is equal to 100% for suggested technique including informative features extraction by both biamplitude and biphase matrices. In our previous investigations [8] and [9] dedicated to human gesture recognition and classification by using parameter P(α) extracted only from biamplitude matrix , the averaged probability of correctly recognition is equal approximately to 85%. Suggested technique using the correlation coefficients provides an averaged probability of correct recognition equal to 95%.

Table 1. Probabilities of true and false human gesture recognition and classification

Type of gesture	"Top-Down"	"Bottom-Up"	"Left to Right"	"Right to Left"
"Top-Down"	100%	0%	0%	0%
"Bottom-Up"	0%	100%	0%	0%
"Left to Right"	0%	0%	100%	0%
"Right to Left"	0%	0%	0%	100%

5. CONCLUSIONS

A novel technique developed for recognition and classification of human gestures is suggested and experimentally examined. It has been demonstrated that proposed bispectrum-based strategy is capable recognizing four test types of the test human gestures with probability approximately equal to 100%. Due to the use of heterodyning, the method is invariant to the speeds of the gestures.

The technique can be used in practice in smart home systems, as a tool for contactless control of indoor lighting, air conditioning, TV, or any other electronic equipment that can be controlled by standard methods. It can also be used to control a computer, in the gaming industry, by replacing a standard mouse or keyboard. Systems based on this method will be useful for people with disabilities who are difficult or impossible to control electronic devices. The method can be useful for use in a car when controlling cabin devices so that the driver is not distracted from the road. This can reduce the number of accidents that occur as a result of distraction the driver from the road.

Proposed technique can be implemented for different radio signals as, for instance: Wi-Fi signals, radio broadcast signals, TV signals or GSM-standard signals. This makes it possible to apply suggested approach in the numerous conditions where the radio emission exists.

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