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Verification and comparison of MIT-BIH arrhythmia database based on number of beats

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ABSTRACT

The ECG signal processing methods are tested and evaluated based on many databases. The most ECG database used for many researchers is the MIT-BIH arrhythmia database. The QRS-detection algorithms are essential for ECG analyses to detect the beats for the ECG signal. There is no standard number of beats for this database that are used from numerous researches. Different beat numbers are calculated for the researchers depending on the difference in understanding the annotation file. In this paper, the beat numbers for existing methods are studied and compared to find the correct beat number that should be used. We propose a simple function to standardize the beats number for any ECG PhysioNet database to improve the waveform database toolbox (WFDB) for the MATLAB program. This function is based on the annotation's description from the databases and can be added to the Toolbox. The function is removed the non-beats annotation without any errors. The results show a high percentage of 71% from the reviewed methods used an incorrect number of beats for this database.

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1. INTRODUCTION

The electrocardiogram (ECG) was generally used for the observation of cardiac physiology as a cost-effective and non-invasive process. For the cardiologist to diagnose cardiac diseases, the ECG signal shows heart functionality. The ECG field is developed significantly, considering the most common death is generally from cardiovascular diseases [1]. Many applications are based on the ECG signal, such as measuring the heart-rate, biometric-identification, movement-recognize, and diagnosing-abnormality [2].

Generally, the first ECG standard material available for testing and performance evaluation is the MIT-BIH arrhythmia database [3]. It played together with the American Heart Association (AHA) database an interesting role in stimulating manufacturers of arrhythmia analyzers to compete on the basis of objectively measurable performance. The value of common databases for basic research and medical device development and evaluation is attributed to the MIT-BIH arrhythmia database. The MIT-BIH has comprised variable ECG signals with a variable: noise, artifacts, beat types, and wave shapes. A 48-records with two channels for each ECG-signal and an annotation file are included. These signals are recording from 25 men and 22 women for a half-hour period at 360 samples per second. The database has been annotated with 112,647 annotations, and these annotations have been verified [3]. It has been classified into two main annotation categories: the beats and the non-beats. The beat annotations for the MIT-BIH arrhythmia database consist of 15 subtypes, and the non-beats annotations consist of 24 subtypes, as shown in Table 1.

The beat type consists of 14 classified beats types and one unclassified beats type. The beats annotations are occurring for any type of QRS waves in ECG-signal. Therefore, this database is widely used for testing, performance evaluating, and learning for QRS-detection methods. In general, the databases are used to evaluate any new algorithm's performance before implementing it in devices for many applications. So, any errors for this evaluation will cause an error in the device decision. In biomedical applications like QRS-detection, which is substantial for many ECG monitoring devices, the detecting errors for these devices may affect doctor's diagnosis and treatment depending on these devices. So, verifying the database for these applications will improve the doctor's decision.

Table 1. The description of beat and non-beat annotations for MIT-BIH arrhythmia database

Beat annotations		Non-beat annotations	
Code	Description	Code	Description
N	Normal beat	[	Start of ventricular flutter/fibrillation
L	Left bundle branch block beat	!	Ventricular flutter wave
R	Right bundle branch block beat	]	End of ventricular flutter/fibrillation
A	Atrial premature beat	x	Non-conducted P-wave (blocked APC)
a	Aberrated atrial premature beat	(N	Normal sinus rhythm
J	Nodal (junctional) premature beat	(P	Paced rhythm
S	Supraventricular premature or ectopic beat (atrial or nodal)	(B	Ventricular bigeminy
V	Premature ventricular contraction	(VT	Ventricular tachycardia
F	A fusion of ventricular and normal beat	(T	Ventricular trigeminy
e	Atrial escape beat	(SVTA	Supraventricular tachyarrhythmia
j	Nodal (junctional) escape beat	(IVR	Idioventricular rhythm
E	Ventricular escape beat	(NOD	Nodal (A-V junctional) rhythm
/	Paced beat	(AFIB	Atrial fibrillation
f	A fusion of paced and normal beat	(AFL	Atrial flutter
Q	Unclassifiable beat	(VFL	Ventricular flutter
		(AB	Atrial bigeminy
		(PREX	Pre-excitation (WPW)
		(BII	2° heart block
		(SBR	Sinus bradycardia
		|	Isolated QRS-like artifact
		~	Change in signal quality
		":TS	Tape slippage
		":PSE	Pause
		":MISSB	Missed beat

Until now, more than two thousand works cited the MIT-BIH arrhythmia database. It is unique in terms of arrhythmia classification since it offers five arrhythmia standards groups [2]. The QRS detection methods are essential for most of the cited works, including arrhythmia detection, classification, and diagnosing applications. Depending on this database, many QRS detection algorithms have been developed, tested, and evaluated. The QRS detection algorithms are based on the beats annotations in the database signals for testing and evaluation. These beats are used as learning data for the methods depending on the learning technique.

Many researchers used MATLAB for algorithm implementation based on the waveform database (WFDB) Toolbox [4]. This Toolbox consists of the functions that are used for reading, writing, and signals processing the files of PhysioNet databases. The MIT-BIH arrhythmia is one of the PhysioNet databases which contains data and annotations files. The WFDB is used to extract the ECG-signals and these annotations from the MIT-BIH arrhythmia database for all records. It can extract one type of beats or non-beats annotations or extract all annotations without any filter. So, it is not easy to extract all beat annotations only, which is leads to errors from reading the non-beat annotations. When reviewing the existing methods that used the MIT-BIH arrhythmia database, we noted that not all these methods are considered the same number of beats for the same database records. Also, this difference affects even slightly the evaluation results used to compare the performance of the methods.

This work will study the reasons for reading different numbers of beats and methods comparison with correction and verification. Furthermore, a new function is designed to extract the correct beats and remove the non-beats annotations from the original database files based on WFDB Toolbox for MATLAB.

In section 2, the MIT-BIH arrhythmia database and its annotation types in detail are described. Section 3 present the proposed function that extracts the correct beat from the annotation files. Then, section 4 demonstrates the results and discussion for revising the existing methods with a comparison based on each method's beat number. Finally, in section 5, the conclusion is summarized.

2. MIT-BIH ARRHYTHMIA DATABASE

The MIT-BIH arrhythmia database is one of the most substantial ECG databases. Contrasting database signals, noise, and artifacts make it suitable for testing and evaluation. Moreover, the verified annotations files that contain the beats and non-beats types, as shown in Table 2 and Table 3. These tables show the MIT-BIH arrhythmia database annotations for each record based on the PhysioNet annotations descriptions for beats and non-beats annotations. There are more than these annotation types, which are shown in other databases.

Table 2. MIT-BIH arrhythmia database beat annotations

Record No.	Total Anno-tations	N	L	R	A	a	J	S	V	F	e	j	E	/	f	Q	Total Beats
100	2274	2239			33				1								2273
101	1874	1860			3											2	1865
102	2192	99							4					2028	56		2187
103	2091	2082			2												2084
104	2311	163							2					1380	666	18	2229
105	2691	2526							41							5	2572
106	2098	1507							520								2027
107	2140								59					2078			2137
108	1824	1739			4				17	2		1					1763
109	2535		2492						38	2							2532
111	2133		2123						1								2124
112	2550	2537			2												2539
113	1796	1789				6											1795
114	1890	1820			10		2		43	4							1879
115	1962	1953															1953
116	2421	2302			1				109								2412
117	1539	1534			1												1535
118	2301			2166	96				16								2278
119	2094	1543							444								1987
121	1876	1861			1				1								1863
122	2479	2476															2476
123	1519	1515							3								1518
124	1634			1531	2		29		47	5		5					1619
200	2792	1743			30				826	2							2601
201	2039	1625			30	97	1		198	2		10					1963
202	2146	2061			36	19			19	1							2136
203	3108	2529				2			444	1						4	2980
205	2672	2571			3				71	11							2656
207	2385		1457	86	107				105				105				1860
208	3040	1586						2	992	373						2	2955
209	3052	2621			383				1								3005
210	2685	2423				22			194	10			1				2650
212	2763	923		1825													2748
213	3294	2641			25	3			220	362							3251
214	2297		2003						256	1						2	2262
215	3400	3195			3				164	1							3363
217	2280	244							162					1542	260		2208
219	2312	2082			7				64	1							2154
220	2069	1954			94												2048
221	2462	2031							396								2427
222	2634	2062			208		1					212					2483
223	2643	2029			72	1			473	14	16						2605
228	2141	1688			3				362								2053
230	2466	2255							1								2256
231	2011	314		1254	1				2								1571
232	1816			397	1382							1					1780
233	3152	2230			7				831	11							3079
234	2764	2700					50		3								2753
Total	112647	75052	8075	7259	2546	150	83	2	7130	803	16	229	106	7028	982	33	**109,494**

Each beat's annotation is a QRS-complex with different types as normal-beat or other beats. On the other hand, The Non-beat annotations are ventricular flutter wave, start/end of ventricular flutter, and starting for many types of rhythm like (sinus, paced, ventricular, supraventricular, atrial fibrillation, atrial flutter, and heart block). These are annotated ECG signal to show at this point one of the rhythms are starting. So, it is not a beats (QRS) annotation. The ventricular flutter (record 207) is excepted for many QRS-detection methods because it is defined on the ECG by a sinusoidal wave without a clear showing of the QRS-complex wave and T wave. The QRS detection methods based on the MIT-BIH arrhythmia database use the beat annotation only because the non-beats annotations are not shown QRS waves for testing, evaluation, and learning.

The number of beats annotations are shown in Table 2 with (109,494 Beats) for all 48 records. This number should be a standard number of beats depending on the original database annotation details and the PhysioNet annotations descriptions for beats and non-beats types. Also, the QRS detection methods are excluded from the 472 ventricular flutter waves from record no. 207, because these waves are considered as non-beat annotations based on the annotation's description of PhysioNet as shown in Table 3.

Table 3. MIT-BIH arrhythmia database non-beat annotations

Record No.	Total Anno-tations	[	!	]	x	(N	(P	(B	(VT	(T	(SVTA	(IVR	(NOD	(AFIB	(AFL	(VFL	(AB	(PREX	(BII	(SBR	|	~	":TS	":PSE	":MISSB	Total Non-Beats
100	2274					1																				1
101	1874					1															4	4				9
102	2192					2	3																			5
103	2091					1																6				7
104	2311					22	23															37				82
105	2691					1															30	88				119
106	2098					21		18	1	1												30				71
107	2140						1															2				3
108	1824				11	1															8	41				61
109	2535					1																2				3
111	2133					1																8				9
112	2550					1																10				11
113	1796					1																				1
114	1890					2					1										1	7				11
115	1962					1															6	2				9
116	2421					1																8				9
117	1539					1																3				4
118	2301				10	1																12				23
119	2094					49		37		17												4				107
121	1876					1																12				13
122	2479					1															2					3
123	1519					1																				1
124	1634					6				2		3	2									2				15
200	2792					70		71	7													43				191
201	2039				37	16				12	1		3	3								4				76
202	2146					3								4	1						2					10
203	3108								21	1				21	2						26	57				128
205	2672					7			6												1	2				16
207	2385	6	472	6		10		4	2		1	1				6					2	15				525
208	3040					27				26											8	24				85
209	3052					11					10										7	19				47
210	2685							5	2	1				9							1	17				35
212	2763					1															1	13				15
213	3294					22		19	2																	43
214	2297					13			2	10											5	4	1			35
215	3400					3			2													30	2			37
217	2280						33	9	1					24							1	4				72
219	2312				133	8		2		1				10										3	1	158
220	2069					9					8											4				21
221	2462							1	2	8				12								12				35
222	2634					32					4		31	24	42		3					15				151
223	2643					11		7	7	3												10				38
228	2141					21		20													24	20	3			88
230	2466					104												103			1	2				210
231	2011				2	6													5						427	440
232	1816																			1		35				36
233	3152					36		28	6	1											2					73
234	2764					2					1											8				11
Total	112647	6	472	6	193	530	60	221	61	83	26	4	36	107	45	6	3	103	5	1	132	616	6	3	428	3153

3. HEARTBEATS FILTER FUNCTION

In this paper, a MATLAB function is designed to filter the annotations file for any PhysioNet databases included the MIT-BIH arrhythmia. The function removes the non-beat annotation shown in Table 3 so, the annotations file will contain the beat annotation only shown in Table 2. On the other hand, the existing

MATLAB-WFDB function (rdann) reading the annotations file can read all annotations or one annotation. So, rdann cannot filter the annotation by beats or non-beats type; for this reason, the function with new features was proposed with new features to filter the data correctly without any errors.

This function is simple, but it is important to standardize the beats number for any researcher that are used PhysioNet databases. This function can be added to the MATLAB-WFDB toolbox to simply filtered the annotations files by removing the non-beat annotations precisely with the standard values. The function read and search all annotations data files for each record, as shown in Figure 1. If the annotation is one of the non-beat types, this annotation will be removed from the annotation data. Also, it has to be used for any PhysioNet database to extract the beat annotation by removing the non-beat annotations used to prepare the data for many applications, including QRS-detection methods.

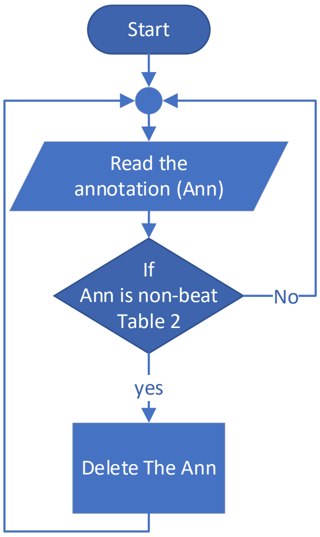

Figure 1. The function flowchart

4. THE COMPARISON AND VERIFICATION RESULTS WITH DISCUSSION

The work focuses on the verification and comparison of the MIT-BIH arrhythmia database used for the QRS-detection algorithm. The proposed heartbeats filter function can apply to all MIT-BIH databases from the PhysioNet site. The reviewed QRS-detection methods are not using the same number of heartbeats for the MIT-BIH arrhythmia database. This number should be standard for this database because it depends on the original database's beats number. Simultaneously, not all the QRS-detection methods are considering the same number of beats for the same database records. The revision for the existing QRS-detection methods using the MIT-BIH arrhythmia database has summarized the errors for these methods based on the beats for records shown in Table 4 (see in Appendix). The incorrect records are indicated by bold, the Total (T), and Errors (E) in this table. The methods should use the same number of beats without any difference, but the errors are occurring by researchers. All the reviewed methods are revised, compared, and verified based on beats number for each database record. Table 5 summarizes the total beats number, total error per record, and total error per database for different methods to evaluate these methods' incorrectness.

The total number of beats for the MIT-BIH arrhythmia database used from the reviewed methods is calculated; this number should be 109,494 heartbeats for all database records, as shown in section 2. The beat errors for these methods compared to the correct number of beats for this database are determined to find the number of methods that used the correct beat's value. Also, the other methods contained errors start from 1 beat to 1400 beats for the overall database. Table 5 shows the percentage of references number for each error per the total references that were reviewed. Moreover, it shows the total number of errors for each reference per each record (sum of the absolute values of errors) and the total number of errors for each reference per overall database, which takes a positive or negative value.

The beats errors per all data record up to 1400 beats and 29% of the total reviewed methods use the correct beats number. On the other hand, 71% are using incorrect beats number. Also, the number of incorrect methods is higher than the number of correct methods based on our comparison. So, we propose this study. Each record in the database for the reviewed methods has been studied for beats errors calculation.

Figure 2 describes the number of references that contain errors for each record. For each record, the percentage of the reference number that occurs error per all references is calculated to evaluate the record error reasons. The records error percentage is started from 53% for record no. 207 to 9% for records (102, 103, 112, 117, 119, 122, 123, and 230).

Table 5 and Figure 2 show the difference between these methods for the same records used from the same database. After the results are studied, the following obvious points are established:

a. The correct number of the beats is 109,494 beats without adding or removing any data.
b. The designed function extracts the correct heartbeats number of all records for the MIT-BIH arrhythmia database.
c. If the beats number exceed the correct number:
   - Some non-beat annotations have been added and should be mentioned in the methods.
   - The data has been repeated for record and should be mentioned in the methods.
d. If the beats number less than the correct number:
   - Some beat annotations have been removed and should be mentioned in the methods.
e. This database contains some errors before digitalization and verification [1].
f. The WFDB toolbox does not include the beats or non-beats filter for the (rdann) function that reads the annotations files.
g. The copy and paste records beat numbers between the researchers without verification.
h. A high number of annotation types (39 annotations) confuse the researchers.
i. According to Figure 2, the most error occurs in record no. 207 because many researchers are counting the 472 ventricular flutter waves, but these waves are considered as non-beat annotations based on the annotation's description of PhysioNet.
j. From Figure 2, records no. 209 is the second, and records no. 214 is the third most errors beats for the reviewed methods, but the number of errors is low and not exceeds eight beats and nine beats, respectively.
k. According to Figure 2, the lowest error records (102, 103, 112, 117, 119, 122, 123, and 230) because these records contain the lowest non-beat annotations.

Table 5. Total beat annotations and errors for the reviewed methods

References	Count of ref	Percentage ref	Total beats	Total errors per record	Total Errors per database
[5-24]	20	29%	109494	0	0
[25]	1	1%	109493	1	-1
[26-31]	6	9%	109496	2	2
[32]	1	1%	109495	3	1
[33]	1	1%	109488	6	-6
[34]	1	1%	109488	6	-6
[35]	1	1%	109486	8	-8
[36]	1	1%	109481	13	-13
[37-39]	3	4%	109508	16	14
[40-42]	3	4%	109510	18	16
[43]	1	1%	109483	23	-11
[44]	1	1%	109488	36	-6
[45]	1	1%	109478	44	-16
[46]	1	1%	109443	51	-51
[47]	1	1%	109428	66	-66
[48]	1	1%	109328	166	-166
[49]	1	1%	109357	203	-137
[50]	1	1%	109255	239	-239
[51-56]	6	9%	109809	329	315
[57]	1	1%	109788	348	294
[58]	1	1%	109267	357	-227
[59]	1	1%	109134	360	-360
[60]	1	1%	109097	423	-397
[61-63]	3	4%	109966	472	472
[64]	1	1%	109965	473	471
[65]	1	1%	109966	474	472
[66]	1	1%	109996	502	502
[67]	1	1%	109369	567	-125
[68]	1	1%	109985	579	491
[69]	1	1%	109663	603	169
[70]	1	1%	110159	665	665
[71]	1	1%	110008	738	514
[72]	1	1%	109036	1400	-458
Total	68	100%			

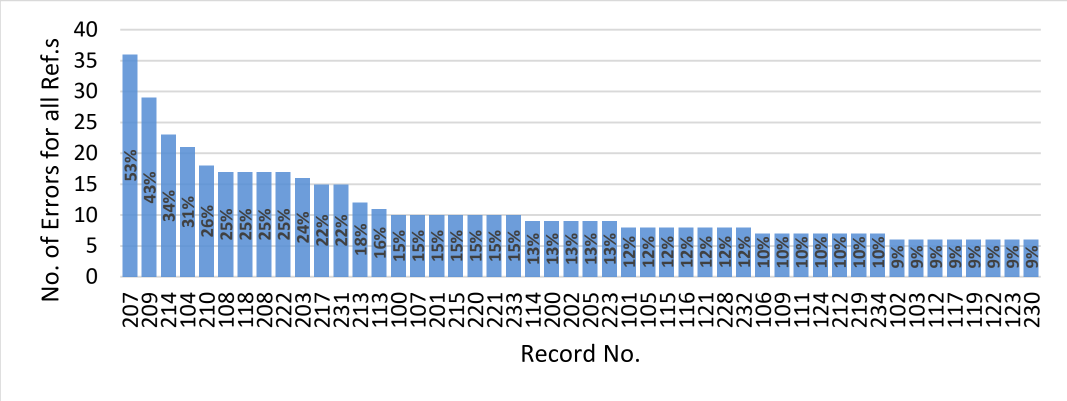

Figure 2. Records errors per overall references

5. CONCLUSION

This paper presented a method for finding the correct beats number for the MIT-BIH arrhythmia database with a comparison study and design a function for MATLAB to extract the correct values for any PhysioNet databases. In this way, the number of beats that are using by the researchers will be standards. The non-beat annotations affected the results of the QRS-detection methods in two ways. First, the proposed methods' evaluation accuracy is not calculated correctly because the number of database beats is incorrect. Second, the methods based on machine learning are trained depending on incorrect information. So, the learning operation was not proper, and the results of the methods are not correct. Most reviewed methods used an incorrect number of beats, 29% of researchers used the correct number, and 71% are used incorrect beats. The proposed function should be added to the MATLAB-WFDB Toolbox to filter the annotations files to remove the non-beat annotations correctly and extract the standard beat values. It can be used for any other programing language to read the annotations files from the PhysioNet databases like python.

APPENDIX

Table 4. The beat annotation for the reviewed methods

Rec	[5-24]	[25]	[26-30]	[31]	[32]	[33]	[34]	[35]	[36]	[37-39]	[40-42]	[43]	[44]	[45]	[46]	[47]	[48]
100	2273	2273	2273	2273	2273	2273	**2272**	**2272**	**2272**	2273	2273	2273	2273	2273	**2271**	2273	**2272**
101	1865	1865	1865	1865	1865	1865	1865	1865	1865	1865	1865	1865	1865	1865	**1864**	1865	**1864**
102	2187	2187	2187	2187	2187	2187	2187	2187	2187	2187	2187	2187	2187	2187	**2186**	2187	2187
103	2084	2084	2084	2084	2084	2084	2084	2084	2084	2084	2084	2084	2084	2084	**2083**	2084	2084
104	2229	2229	2229	2229	2229	2229	**2228**	**2228**	**2228**	2229	2229	2229	2229	**2230**	**2228**	2229	**2227**
105	2572	2572	2572	2572	2572	2572	2572	2572	2572	2572	2572	2572	2572	2572	**2571**	2572	**2555**
106	2027	2027	2027	2027	2027	2027	2027	2027	2027	2027	2027	2027	2027	2027	**2026**	2027	2027
107	2137	**2136**	2137	2137	2137	2137	2136	2137	2137	2137	2137	2137	2137	2137	**2136**	2137	**2135**
108	1763	1763	1763	1763	1763	1763	1763	1763	1763	**1774**	**1774**	**1760**	**1774**	1763	**1762**	1763	**1761**
109	2532	2532	2532	2532	2532	2532	2532	2532	2532	2532	2532	2532	2532	2532	**2531**	2532	2532
111	2124	2124	2124	2124	2124	2124	2124	2124	2124	2124	2124	2124	2124	2124	**2123**	2124	2124
112	2539	2539	2539	2539	2539	2539	2539	2539	2539	2539	2539	2539	2539	2539	**2538**	2539	2539
113	1795	1795	1795	1795	1795	1795	**1794**	**1794**	**1794**	1795	1795	1795	1795	1795	**1793**	1795	**1794**
114	1879	1879	1879	1879	1879	1879	1879	**1878**	1879	1879	1879	**1872**	1879	1879	**1878**	1879	1879
115	1953	1953	1953	1953	1953	1953	1953	1953	1953	1953	1953	**1952**	1953	1953	**1952**	1953	**1952**
116	2412	2412	2412	2412	2412	2412	2412	2412	2412	2412	2412	2412	2412	2412	**2411**	2412	**2410**
117	1535	1535	1535	1535	1535	1535	1535	1535	1535	1535	1535	1535	1535	1535	**1534**	1535	1535
118	2278	2278	2278	2278	2278	2278	2278	2278	**2277**	2278	2278	2278	2278	**2288**	**2277**	2278	2278
119	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	1987	**1986**	1987	1987
121	1863	1863	1863	1863	1863	1863	1863	**1862**	**1862**	1863	1863	1863	1863	1863	**1862**	1863	1863
122	2476	2476	2476	2476	2476	2476	2476	2476	2476	2476	2476	2476	2476	2476	**2475**	2476	2476
123	1518	1518	1518	1518	1518	1518	1518	1518	1518	1518	1518	1518	1518	1518	**1517**	1518	1518
124	1619	1619	1619	1619	1619	1619	1619	1619	1619	1619	1619	1619	1619	1619	**1618**	1619	1619
200	2601	2601	2601	2601	2601	2601	2601	2601	2601	2601	2601	2601	2601	2601	**2600**	2601	**2581**
201	1963	1963	1963	1963	1963	1963	1963	1963	**1962**	1963	1963	1963	1963	1963	**1962**	1963	**1950**
202	2136	2136	2136	2136	2136	**2135**	2136	2136	2136	2136	2136	2136	2136	2136	**2135**	2136	**2133**
203	2980	2980	2980	2980	2980	2980	2980	2980	2980	2980	2980	2980	2980	2980	**2979**	2980	**2949**
205	2656	2656	2656	2656	2656	2656	2656	2656	**2655**	2656	2656	2656	2656	2656	**2655**	2656	**2647**
207	1860	1860	**1862**	1860	**1862**	1860	1860	1860	1860	1860	**1862**	**1862**	1860	**1862**	**1859**	**1794**	**1859**

Table 4. The beat annotation for the reviewed methods (*continue)*

Rec	[5-24]	[25]	[26-30]	[31]	[32]	[33]	[34]	[35]	[36]	[37-39]	[40-42]	[43]	[44]	[45]	[46]	[47]	[48]
208	2955	2955	2955	2955	2955	2955	2955	2955	2955	2955	2955	2955	2955	**2946**	**2954**	2955	**2921**
209	3005	3005	3005	**3004**	3005	**3004**	3005	**3004**	**3004**	**3004**	**3004**	**3004**	**3004**	3005	**3004**	3005	**3002**
210	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	**2647**	**2649**	2650	**2644**
212	2748	2748	2748	2748	2748	2748	2748	2748	2748	2748	2748	2748	2748	2748	**2747**	2748	**2747**
213	3251	3251	3251	3251	3251	3251	**3250**	**3250**	**3250**	3251	3251	3251	3251	3251	**3249**	3251	**3249**
214	2262	2262	2262	**2261**	**2261**	**2261**	2262	**2261**	**2261**	**2265**	**2265**	**2265**	**2265**	**2254**	**2261**	2262	**2261**
215	3363	3363	3363	3363	3363	**3361**	3363	3363	3363	3363	3363	3363	3363	**3353**	**3362**	3363	**3362**
217	2208	2208	2208	2208	2208	2208	2208	2208	2208	**2209**	**2209**	**2209**	**2209**	2208	**2207**	2208	2208
219	2154	2154	2154	2154	2154	2154	2154	2154	2154	2154	2154	2154	2154	2154	**2153**	2154	2154
220	2048	2048	2048	2048	2048	2048	**2047**	2048	**2047**	2048	2048	2048	2048	2048	**2047**	2048	**2047**
221	2427	2427	2427	2427	2427	2427	2427	2427	**2426**	2427	2427	2427	**2407**	2427	**2426**	2427	2427
222	2483	2483	2483	2483	2483	2483	2483	2483	2483	2483	2483	2483	2483	**2484**	**2482**	2483	**2482**
223	2605	2605	2605	2605	2605	2605	2605	2605	2605	2605	2605	2605	2605	2605	**2604**	2605	**2603**
228	2053	2053	2053	2053	2053	2053	2053	2053	2053	2053	2053	**2048**	2053	2053	**2052**	2053	2053
230	2256	2256	2256	2256	2256	2256	2256	2256	2256	2256	2256	2256	2256	2256	**2255**	2256	2256
231	1571	1571	1571	1571	1571	1571	1571	1571	1571	1571	1571	1571	1571	1571	**1570**	1571	1571
232	1780	1780	1780	1780	1780	**1779**	1780	1780	1780	1780	1780	1780	1780	1780	**1779**	1780	1780
233	3079	3079	3079	3079	3079	3079	3079	3079	**3078**	3079	3079	3079	3079	3079	**3078**	3079	**3071**
234	2753	2753	2753	2753	2753	2753	2753	2753	2753	2753	2753	2753	2753	2753	**2752**	2753	2753
T	109494	109493	109496	109492	109495	109488	109488	109486	109481	109508	109510	109483	109488	109478	109443	109428	109328
E	0	1	2	2	3	6	6	8	13	16	18	23	36	44	51	66	166

Rec	[49]	[50]	[51-56]	[57]	[58]	[59]	[60]	[61-63]	[64]	[65]	[66]	[67]	[68]	[69]	[70]	[71]	[72]
100	**2269**	2273	2273	2273	**2267**	**2265**	2273	2273	2273	2273	2273	2273	**2274**	**2270**	2273	2273	**2272**
101	**1862**	**1864**	1865	1865	**1859**	**1860**	1865	1865	1865	1865	1865	1865	**1866**	**1862**	1865	**1873**	**1864**
102	**2183**	2187	2187	2187	**2181**	**2180**	2187	2187	2187	2187	2187	2187	2187	**2186**	2187	**2186**	**2186**
103	**2081**	2084	2084	2084	**2081**	**2078**	2084	2084	2084	2084	2084	2084	2084	**2083**	2084	2084	**2083**
104	**2225**	**2226**	**2230**	**2230**	**2224**	**2222**	**2230**	2229	2229	**2230**	2229	2229	2229	**2219**	2229	**2235**	**2228**
105	**2582**	**2566**	2572	2572	**2564**	**2565**	2572	2572	2572	2572	2572	2572	**2602**	**2559**	2572	**2578**	**2571**
106	**2024**	**2023**	2027	2027	**2024**	**2021**	2027	2027	2027	2027	2027	2027	**2026**	**2025**	2027	**2096**	**2026**
107	**2133**	**2135**	2137	2137	**2131**	**2131**	2137	2137	2137	2137	2137	2137	**2136**	**2135**	2137	**2138**	**2136**
108	**1761**	**1759**	1763	1763	**1757**	**1757**	1763	1763	1763	1763	1763	1763	1763	**1747**	**1774**	1763	**1762**
109	**2528**	**2527**	2532	2532	**2526**	**2524**	2532	2532	2532	2532	2532	2532	**2533**	**2531**	2532	**2519**	**1649**
111	**2121**	**2123**	2124	2124	**2120**	**2118**	2124	2124	2124	2124	2124	2124	**2123**	**2120**	2124	2124	**2123**
112	**2535**	2539	2539	2539	**2536**	**2531**	2539	2539	2539	2539	2539	2539	2539	**2537**	2539	**2549**	**2538**
113	**1791**	1795	1795	**1797**	**1791**	**1789**	1795	1795	1795	1795	1795	1795	**1794**	**1792**	1795	1795	**1794**
114	**1875**	**1832**	1879	1879	**1872**	**1872**	1879	1879	1879	1879	1879	1879	**1890**	**1878**	1879	**1885**	**1878**
115	**1949**	1953	1953	1953	**1945**	**1946**	1953	1953	1953	1953	1953	1953	1953	**1950**	1953	**1960**	**1952**
116	**2408**	**2392**	2412	2412	**2409**	**2404**	2412	2412	2412	2412	2412	2412	**2395**	**2407**	2412	**2401**	**2411**
117	**1532**	1535	1535	1535	**1532**	**1530**	1535	1535	1535	1535	1535	1535	1535	**1534**	1535	**1538**	**1534**
118	**2275**	2278	**2275**	**2275**	**2273**	**2271**	**2275**	2278	2278	2278	2278	2278	2278	**2275**	**2288**	**2298**	**2277**
119	**1984**	1987	**1987**	**1987**	**1985**	**1981**	1987	1987	1987	1987	1987	1987	**1988**	**1985**	1987	**2010**	**1986**
121	**1859**	1863	1863	1863	**1858**	**1856**	1863	1863	1863	1863	1863	1863	1863	**1860**	1863	**1871**	**1862**
122	**2472**	2476	2476	2476	**2471**	**2468**	2476	2476	2476	2476	2476	2476	2476	**2475**	2476	**2477**	**2475**
123	**1515**	1518	1518	1518	**1514**	**1513**	1518	1518	1518	1518	1518	1518	**1519**	**1517**	1518	1518	**1517**
124	**1616**	1619	1619	1619	**1613**	**1613**	1619	1619	1619	**1618**	1619	1619	1619	**1618**	1619	**1602**	**1618**
200	**2597**	**2600**	2601	2601	**2595**	**2593**	**2607**	2601	2601	2601	2601	2601	2601	**2560**	2601	**2599**	**2600**
201	**1961**	**1934**	1963	1963	**1946**	**1959**	1963	1963	1963	1963	1963	1963	**1949**	**1954**	**2000**	1963	**1962**
202	**2132**	**2132**	2136	2136	**2134**	**2128**	2136	2136	2136	2136	2136	2136	**2138**	**2134**	2136	**2135**	**2135**
203	**3003**	**2926**	**2982**	**2978**	**2976**	**2973**	**2982**	2980	2980	2980	2980	2980	**2988**	**2962**	2980	**2982**	**2979**
205	**2652**	**2653**	2656	2656	**2650**	**2648**	2656	2656	2656	2656	2656	2656	2656	**2654**	2656	**2657**	**2655**
207	**1855**	**1857**	**1862**	**1862**	**1856**	**1850**	**1862**	**2332**	**2332**	**2332**	**2332**	**1543**	**2324**	**2246**	**2332**	**1862**	**2331**
208	**2951**	**2940**	**2956**	**2954**	**2953**	**2946**	**2956**	2955	2955	2955	2955	2955	**2953**	**2937**	2955	**2952**	**2954**
209	**3001**	3005	**3004**	**3004**	**2999**	**2997**	**3004**	3005	**3004**	3005	3005	**3006**	**3006**	**3002**	3005	**3051**	**3004**
210	**2646**	**2628**	**2647**	**2647**	**2645**	**2642**	**2647**	2650	2650	2650	2650	**2640**	**2652**	**2640**	2650	**2645**	**2649**
212	**2744**	2748	2748	2748	**2746**	**2740**	2748	2748	2748	2748	2748	2748	2748	**2746**	2748	**2761**	**2747**
213	**3246**	**3250**	3251	3251	**3245**	**3241**	3251	3251	3251	3251	3251	**3471**	**3250**	**3247**	3251	**3245**	**3250**
214	**2258**	**2258**	2262	2262	**2255**	**2254**	2262	2262	2262	2262	2262	**2259**	2262	**2259**	2262	**2273**	**2261**
215	**3358**	3363	3363	**3362**	**3357**	**3353**	3363	3363	3363	3363	3363	3363	**3362**	**3360**	3363	**3398**	**3362**
217	**2205**	**2207**	2208	2208	**2202**	**2202**	2208	2208	2208	2208	2208	2208	2208	**2207**	2208	**2270**	**2207**
219	**2151**	2154	2154	2154	**2150**	**2147**	2154	2154	2154	2154	2154	2154	2154	**2152**	**2287**	2154	**2153**
220	**2044**	**2047**	2048	2048	**2041**	**2041**	2048	2048	2048	2048	2048	2048	2048	**2047**	2048	**2068**	**2047**
221	**2423**	**2426**	2427	2427	**2422**	**2420**	2427	2427	2427	2427	**2457**	2427	2427	**2426**	2427	**2447**	**2426**
222	**2478**	**2481**	**2484**	**2484**	**2492**	**2474**	**2484**	2483	2483	2483	2483	2483	**2485**	**2481**	2483	**2624**	**2482**
223	**2601**	**2604**	2605	2605	**2603**	**2581**	2605	2605	2605	2605	2605	**2589**	**2604**	**2604**	2605	**2636**	**2604**
228	**2050**	**2050**	2053	2053	**2048**	**2047**	2053	2053	2053	2053	2053	2053	**2060**	**2051**	2053	**2116**	**2052**
230	**2252**	2256	2256	2256	**2252**	**2248**	2256	2256	2256	2256	2256	2256	2256	**2253**	2256	**2257**	**2255**
231	**1568**	1571	**1886**	**1886**	**1566**	**1565**	**1186**	1571	1571	1571	1571	1571	1571	**1570**	**1573**	**1569**	**1570**
232	**1778**	1780	1780	**1767**	**1719**	**1776**	1780	1780	1780	1780	1780	1780	**1783**	**1779**	1780	**1734**	**1779**
233	**3074**	**3078**	3079	**3076**	**3135**	**3069**	3079	3079	3079	3079	3079	3079	**3077**	**3076**	3079	**3074**	**3078**
234	**2749**	2753	2753	2753	**2747**	**2745**	**2735**	2753	2753	2753	2753	2753	**2751**	**2751**	2753	**2763**	**2752**
T	109357	109255	109809	109788	109267	109134	109097	109966	109965	109966	109996	109369	109985	109663	110159	110008	109036
E	203	239	329	348	357	360	423	472	473	474	502	567	579	603	665	738	1400

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