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Music Structure Analysis Statistics for Popular Songs

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Abstract

In this chapter, we have proposed a better procedure for manual annotation of music information. The proposed annotation procedure involves carrying out listening tests and then incorporating music knowledge to iteratively refine the detected music information. Using this annotation technique, we can effectively compute the durations of the music notes, time-stamp the music regions, i.e. pure instrumental, pure vocal, instrumental mixed vocals and silence, and annotate the semantic music clusters (components in a song structure), i.e. Verse -V, Chorus - C, Bridge -B, Intro, Outro and Middle-eighth.
From the annotated information, we have further derived the statistics of music structure information. We conducted experiments on 420 popular songs which were sung in English, Chinese, Indonesian and German languages. We assumed a constant tempo throughout the song and meter to be 4/4. Statistical analysis revealed that 62.46%, 35.48%, 1.87% and 0.17% of the contents in a song belong to instrumental mixed vocal, pure instrumental, silence and pure vocal music regions. We also found over 70% of English and Indonesian songs and 30% of Chinese songs used V-C-V-C and V-V-C-V-C song structures respectively, where V and C denote the verse and chorus respectively. It is also found that 51% of English songs, 37% of Chinese songs, and 35% of Indonesian songs used 8 bar duration in both chorus and verse.

1. Introduction

Music is a universal language people use for sharing their feelings and sensations. Thus there have been keen research interests not only to understand how music information stimulates our minds, but also to develop applications based on music information. For example, vocal and non-vocal music information are useful for sung language recognition systems (Tsai et at., 2004., Schwenninger et al., 2006), lyrics-text and music alignment systems (Wang et al., 2004), mood classification systems (Lu & Zhang, 2006) music genre classification (Nwe & Li, 2007., Tzanetakis & Cook, 2002) and music classification systems (Xu et al., 2005., Burred & Lerch, 2004). Also, information about rhythm, harmony, melody contours and song structures (such as repetitions of chorus verse semantic regions) are useful for developing systems for error concealment in music streaming (Wang et al., 2003), music protection (watermarking), music summarization (Xu et al., 2005), compression, and music search.

Computer music research community has been developing algorithms to accurately extract the information in music. Many of the proposed algorithms require ground truth data for both the parameter training process and performance evaluation. For example, the performance of a music classifier which classify the content in the music segment as vocal or non-vocal, can be improved when the parameters of the classifier are trained with accurate vocal and non-vocal music contents in the development dataset. Also the performance of the classifier can effectively be measured when the evaluation dataset is accurately annotated based on the exact music composition information. However it is difficult to create accurate development and evaluation datasets because it is difficult to find information about the music composition mainly due to copyright restrictions on sharing music information in the public domain. Therefore, the current development and evaluation datasets are created by annotating the information that is extracted using subjective listening tests. Tanghe et al., (2005) discussed an annotation method for drum sounds. In Goto (2006)'s method, music scenes such as beat structure, chorus, and melody line are annotated with the help of corresponding MIDI files. Li, et al., (2006) modified the general audio editing software so that it becomes more convenient for identifying music semantic regions such as chorus. The accuracy of subjective listening test hinges on subject's hearing competence, concentration and music knowledge. For example, it is often difficult to judge the start and end time of vocal phrases when they are presented with strong background music. If the listener's concentration is disturbed, then the listening continuity is lost and then it is difficult to accurately mark the phrase boundaries. However if we know the tempo and meter of the music, then we can apply that knowledge to correct the errors of the phrase boundaries which are detected in the listen tests.

Speed of music information flow is directly proportional to tempo of the music (Authors, 1949). Therefore the duration of music regions, semantic regions, inter-beat interval, and beat positions can be measured as multiples of music notes. The proposed music information annotation technique in this chapter, first locates the beats and onset positions by both listening and visualizing the music signal using a graphical waveform editor. Since the time duration of the detected beat or onset from the start of music is an integer multiple of the duration of a smallest note, we can estimate the duration of the smallest note. Then we carry out intensive listening exercise with the help of estimated durations of the smallest music note to detect the time stamps of music regions and different semantic regions. Using the annotated information, we detect the song structure and calculate the statistics of the music information distributions.

This chapter is organized as follows. Popular music structure is discussed in section 2 and effective information annotation procedures are explained in section 3. Section 4 details the statistics of music information. We conclude the chapter in section 5 with a discussion.

2. Music Structure

As shown in Fig. 1, the underlying music information can conceptually be represented as layers in a pyramid (Maddage, 2005). These information layers are:

1) First layer represents the time information (beats, tempo, and meter);
2) Second layer represents the harmony/melody which is formed by playing musical notes simultaneously;
3) Third layer describes the music regions, i.e. pure vocal (PV), pure instrumental (PI), instrumental mixed vocal (IMV) and silence (S);
4) Forth layer and above represent the semantics of the popular song.

The pyramid diagram represents music semantics which influence our imaginations. Jourdain (1997) also discussed how sound, tone, melody, harmony, composition, performance, listening, understanding and ecstasy lead to our imagination.

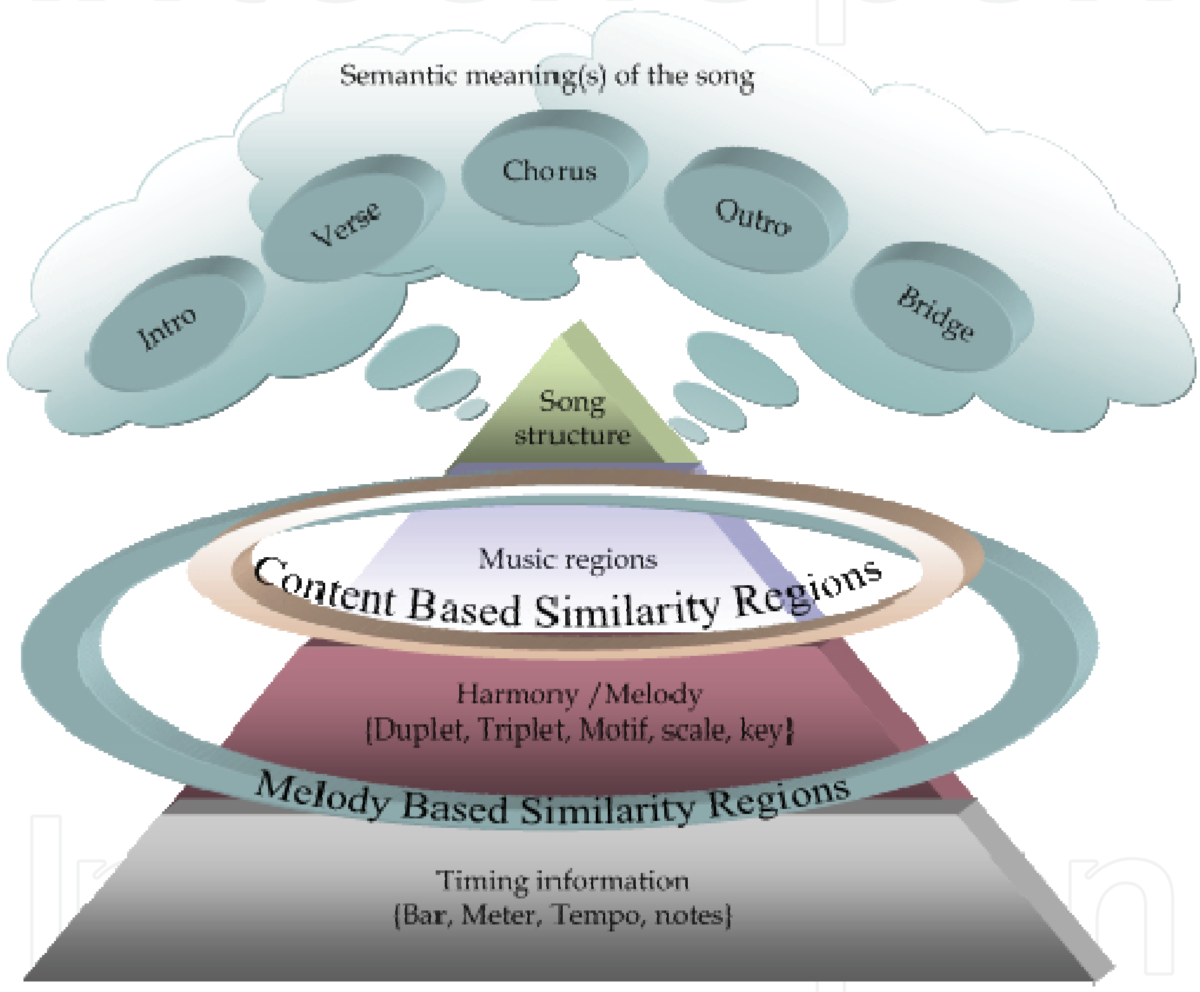


Fig. 1. Information grouping in the music structure pyramid

Time information describes the rate of information flow in music. Durations of Harmony / melody contours and phrases which create music regions are proportional to the tempo of music. *Melody* is created when a single note is played at a time. Playing multiple notes results in harmony sound. Psychological studies have suggested the human cognitive mechanism can effectively distinguish the tones of the diatonic scale (Burred & Lerch, 2004). Scale changes or modulation of the scale in a different section of the song can effectively be

noticed in the listening tests. Therefore, in our listening tests we detect the Middle-eighth regions (see next section) which have a different *Key* from the main *Key* of the song.
The rhythm of words can be tailored to fit into a music phrase (Authors, 1949). The vocal regions in music comprise of words and syllables, which are uttered according to a time signature. Fig. 2 shows how the words "Little Jack Horner sat in the Corner" are turn into a rhythm, and the music notation of those words. The important words or syllables in the sentence fall onto accents to form the rhythm of the music. Typically, these words are placed at the first beat of a bar. When TS is set to two Crotchet beats per bar, we see the duration of the word "Little" is equal to two Quaver notes and the duration of the word "Jack" is equal to a Crotchet note.

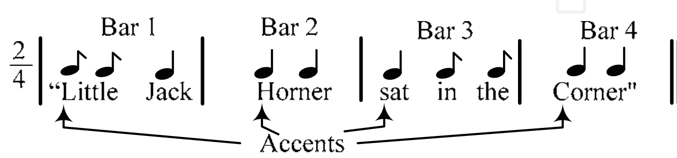


Fig. 2. Rhythmic flow of words

Popular song structure often contains Intro, Verse, Chorus, Bridge, Middle-eighth, instrumental sections (INST) and Outro (Authors, 2003). As shown in Fig. 1, these parts are built on melody-based similarity regions and content-based similarity regions. Melody-based similarity regions are defined as the regions which have similar pitch contours constructed from the chord patterns. Content-based similarity regions are defined as the regions which have both similar vocal content and melody. In terms of music structure, the Chorus sections and Verse sections in a song are considered the content-based similarity regions and melody-based similarity regions respectively. They can be grouped to form semantic clusters as in Fig. 3. For example, all the Chorus regions in a song form a Chorus cluster, while all the Verse regions form a Verse cluster and so on.

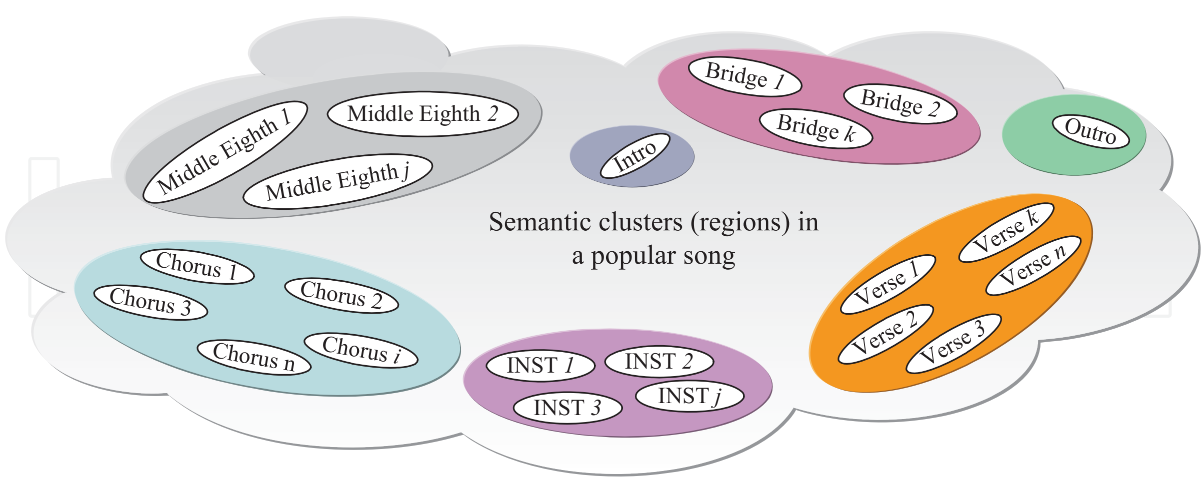


Fig. 3. Semantic similarity clusters which define the structure of the popular song

A song may have an Intro of 2, 4, 8 or 16 bars long, or do not have any at all. The Intro is usually comprised of instrumental music. Both Verse and Chorus are 8 or 16 bars long. Typically, the Verse is not melodically as strong as the Chorus. However, in some songs both verse and chorus are equally melodically strong. Most people can hum or sing both chorus and verse. A Bridge links the gap between the Verse and Chorus, and may have only two or four bars.

Song: 25 Minutes
Artist / Band: MLTR
Song structure: Intro (INST) Verse 1 Verse 2 Bridge Chorus 1 Verse 3 Bridge Chorus 2 Middle eight Chorus 3 Chorus 4 Outro (INST)

Intro: Instrumental (INST)

Verse 1
After some time
I've finally made up my mind
She is the girl
And I really want to make her mine

Verse 2
I'm searching everywhere
To find her again
To tell her I love her
And I'm sorry about the things I've done

Bridge
I find her standing
in front of the church
The only place in town where I didn't search
She looks so happy in her wedding dress
But she's crying while she's saying this

Chorus 1
Boy I've missed your kisses
All the time but this is
Twenty five minutes too late
Though you traveled so far
Boy I'm sorry you are
Twenty five minutes too late

Verse 3
Against the wind
I'm going home again
hummma (humming)
Wishing me back
To the time when we were more than friends

Bridge
But still I see her in front of the church
The only place in town where I didn't search
She looked so happy in her wedding dress
But she cried while she was saying this

Chorus 2
Boy I've missed your kisses
All the time but this is
Twenty five minutes too late
Though you traveled so far
Boy I'm sorry you are
Twenty five minutes too late

Middle Eight
Out in the streets
Places where hungry hearts have nothing to eat
Inside my head
Still I can
hear the words she said

Chorus 3
Boy I've missed your kisses
All the time but this is
Twenty five minutes too late
Though you traveled so far
Boy I'm sorry you are
Twenty five minutes too late

Chorus 4
Boy I've missed your kisses
All the time but this is
Twenty five minutes too late
its too late
Though you traveled so far
Boy I'm sorry you are
Twenty five minutes too late
I can still hear her say…

Outro - Instrumental (INST)

Song : Cant let go
Artist / Band: Mariah Carey
Song structure : Intro (INST) Verse 1 Chorus 1 Verse 2 Chorus 2 Bridge Chorus 3 Outro (INST)

Intro : Instrumental (INST)

Verse 1
There you are,
holding her hand
i am lost,
dying to understand
didnt i,
cherish u right
dont u know,
u were my life.

Chorus 1
even though i try, I cant
let go
something in your eyes
captures
my soul
and everynight i see you in my dreams
you're all i know
i cant let go

Verse 2
just cast aside,
u dont even know i'm alive
u just walk on by,
don't care to see me cry
and here i am
still holding on,
I cant accept
my world is gone
no no...

Chorus 2
even though i try,
i cant
let go,
something in your eyes captures my soul.
and everynight i see you in my dreams,
you're all i know,
i cant let go

Bridge
do you ever realise,
the sorrow i have inside,
everyday of my life.
do you know the way it feels
when all your love just dies,
i try and try to deny that i need you
but still you remain on my mind

Chorus 3
even though i try,
i cant let go
something in your eyes
captures my soul
and everynight i see you
in my dreams
you're all i know
i can't let go...

Outro - Instrumental (INST)

Fig. 4. Two examples for verse- chorus pattern repetitions.

Silence may also act as a Bridge between the Verse and Chorus of a song, but such cases are rare. Middle-eighth, which has 4, 8 or 16 bars in length, is an alternative version of a Verse with a new chord progression possibly modulated by a different key. Many people use the term “Middle-eighth” and “bridge” synonymously. However, the main difference is the middle-eighth is longer (usually 16 bars) than the bridge and usually appears after the third verse in the song. There are instrumental sections in the song and they can be instrumental versions of the Chorus, Verse, or entirely different tunes with a set of chords together. Typically INST regions have 8 or 16 bars. Outro, which is the ending of the song, is usually a fade–out of the last phrases of the chorus. We have described the parts of the song which are commonly arranged according to the simple verse-chorus and repeat pattern. Two variations on these themes are as follows:

(a) Intro, Verse 1, Verse 2, Chorus, Verse 3, Middle-eighth, Chorus, Chorus, Outro

(b) Intro, Verse 1, Chorus, Verse 2, Chorus, Chorus, Outro

Fig. 4 illustrates two examples of the above two patterns. Song, “25 minutes” by MLTR follows the pattern (a) and “Can’t Let You Go” by Mariah Carey follows the pattern (b). For a better understanding of how artist have combined these parts to compose a song, we conducted a survey on popular Chinese and English songs. Details of the survey are discussed in the next section.

3. Music Structure Information Annotation

The fundamental step for audio content analysis is signal segmentation. Within a segment, the information can be considered quasi-stationary. Feature extraction and information modeling followed by music segmentation are the essential steps for music structure analysis. Determination of the segment size, which is suitable for extracting certain level of information, requires better understanding of the rate of information flow in the audio data. Over three decades of speech processing research has revealed that 20-40 ms of fixed length signal segmentation is appropriate for the speech content analysis (Rabiner & Juang, 2005). The composition of music piece reveals the rate of information such as notes, chords, key, vocal phrases, flow is proportional to inter-beat intervals.

Fig. 5 shows the quarter, eighth and sixteenth note boundaries in a song clip. It can be seen that the fluctuation of signal properties in both spectral and time domain are aligned with those note boundaries. Usually smaller notes, such as eighth, sixteenth and thirty-second notes or smaller are played in the bars to align the harmony contours with the rhythm flow of the lyrics and to fill the gap between lyrics (Authors, 1949). Therefore inter-beat proportional music segmentation instead of fixed length segmentation has recently been proposed for music content analysis (Maddage, 2004., Maddage, 2005., Wang, 2004).

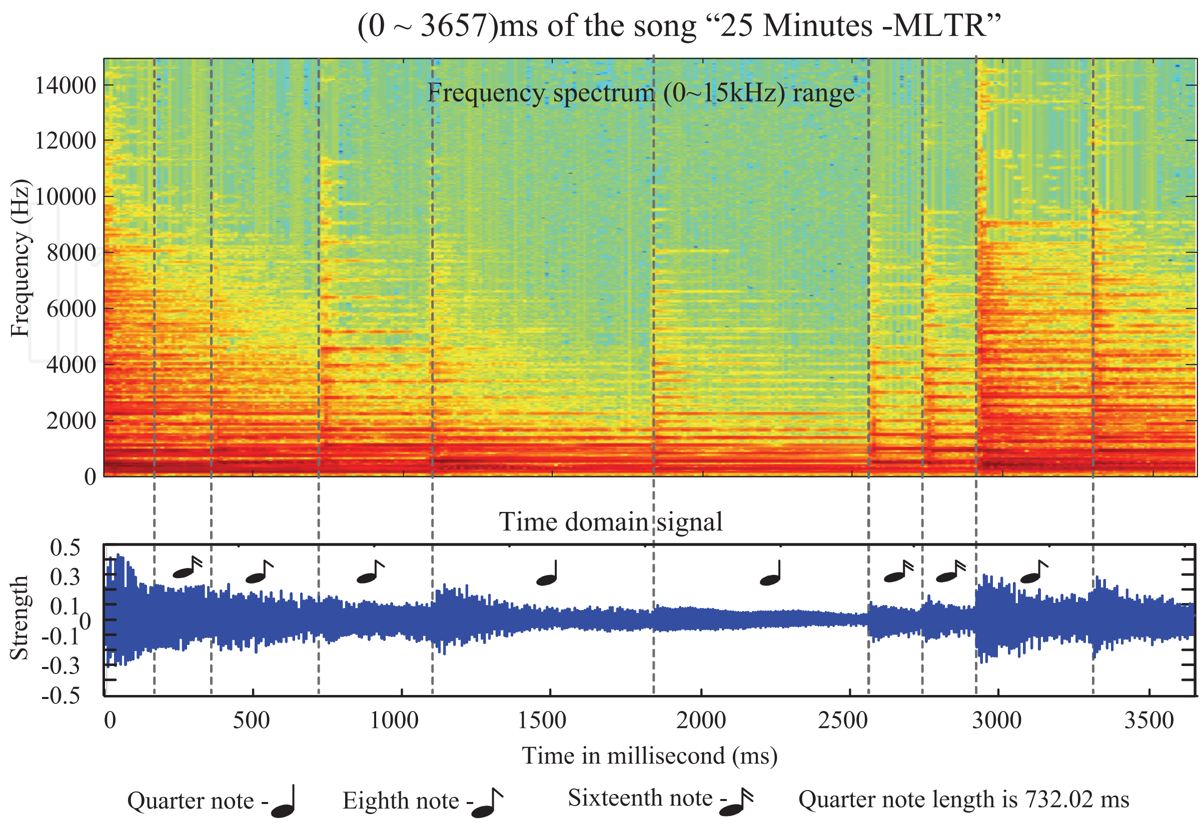


Fig. 5. Spectral and time domain visualization of (0~3657) ms long song clip from "25 Minutes" by MLTR. Quarter note length is 736.28 ms and note boundaries are highlighted using dotted lines.

3.1. Computation of Inter-beat interval

Once the staff of a song is available, from the value of tempo and time signature we can calculate the duration of the beat. However commercially available music albums (CDs) do not provide staff information of the songs. Therefore subjects with a good knowledge of theory and practice of music have to closely examine the songs to estimate the inter-beat intervals in the song. We assume all the songs have 4/4 time signature, which is the commonly used TS in popular songs (Goto, M. 2001, Authors, 2003). Following the results of music composition and structure, as discussed in section 2, we only allow the positions of beats to take place at integer multiple of smaller notes from the start point of the song. Estimation of both inter-beat interval and song tempo using an iterative listening is explained below, with Fig. 6 as an example.

- Play the song in audio editing software which has a GUI to visualize the time domain signal with high resolution. While listening to the music it is noticed that there is a steady throb to which one can clap. This duration of consecutive clapping is called inter-beat interval. As we assume 4/4 time signature which infers that the inter-beat interval is of quarter note length, hence four quarter notes form a bar.
- As shown in Fig. 6, the positions of both beats and note onsets can be effectively visualized on the GUI, and j^{th} position is indicated as P_j. By replaying the song and zooming into the areas of neighboring beats and onset positions, we can estimate the

inter-beat interval and therefore the duration of the note X_j. In Fig. 6, we can see the duration X_1 is the first estimated eighth note.

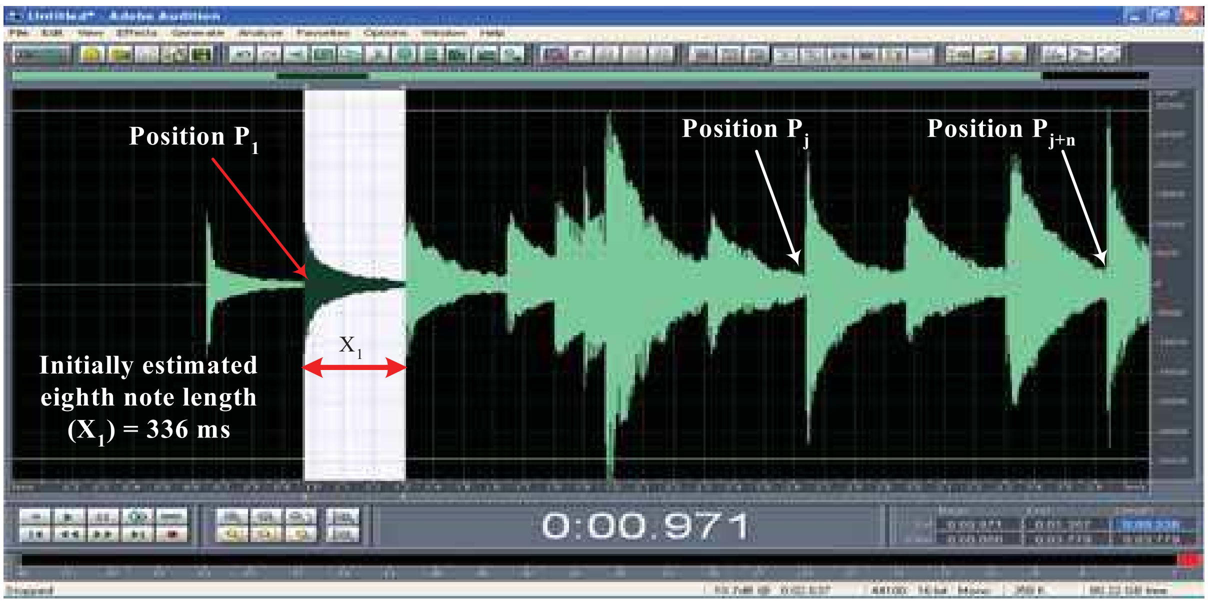


Fig. 6. Estimation of music note

- After the first estimation, we establish a 4-step iterative listening process discussed below to reduce the error between the estimates and the desired music note lengths. The constraint we apply is that beat position is equal to integer multiple of frames. To start with, first frame size is set to the estimated note, i.e. Frame size = X_1 in Fig. 6.

Step 1: Set the currently estimated note length as the frame size; calculate the number of frames NF_j at an identified beat or onset position. For the initialization, we set $j = 1$.

$$NF_j = \frac{P_j}{X_j} \tag{1}$$

Step 2: As the resulting NF_j is typically a floating point value, we measure the difference between round up NF_j and NF_j, referred to as DNF.

$$DNF = \left| NF_j - round\left(NF_j \right) \right| \tag{2}$$

IF $DNF > 0.35$,

This implies, the duration of current beat or onset position P_j is an integer multiple of the frames plus a half a frame. Therefore we set new note length to the half of X_j. For example the new frame size is equal to sixteenth note and if the previous frame was an eighth note. Then go to step 1

ELSE

$$NF_j = round\left(NF_j \right) \tag{3}$$

Step 3: At beat/ onset position P_j, we calculate the new note length X_{j+1} as below.

$$X_{j+1} = \frac{P_j}{NF_j} \tag{4}$$

Step 4: Iterate the step 1 to 3 at beat or onset positions towards the end of the songs. When these iterative steps are carried out over many of the beat and onset positions towards the end of the song, the errors of the estimated note length are minimized. Based on the final length estimate for the note, we can calculate the quarter note length.

Fig. 7 shows the variation of the estimated quarter note length for two songs. Beat/onset positions nearly divide the song into equal intervals. Beat/onset point zero ("0") represents the first estimation of quarter note length. The correct tempos of the songs "You are still one" and "The woman in me" are 67 BPM and 60 BPM respectively.

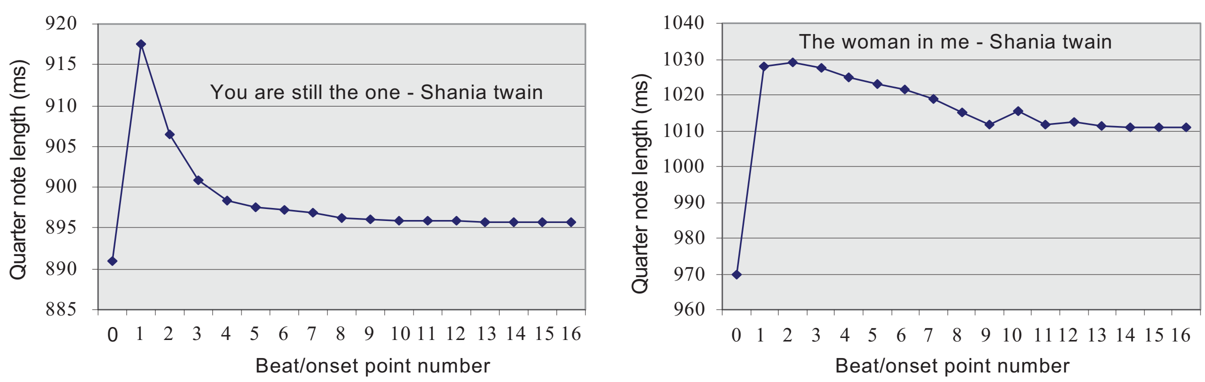


Fig. 7. Variation of estimated length of the quarter note at beat/onset points when the listening test was carried out till the end of the song.

It can be seen in the Fig. 7, that the deviation of the estimated quarter note is high at the beginning of the song. However estimated quarter note converges to the correct value at the second half of the song (end of the song). Reason for the fluctuation of the estimated note length is explained below.

As shown in Fig. 6, first estimation of the note length (X_1) is done using only audio-visual editing software. Thus first estimation (beat/ onset point P = 0 in Fig. 7) can have very high variation due to the prime difficulties of judging the correct boundaries of the notes. When the song proceeds, using Eq, (1), (2), (3) and (4), we iteratively estimate the duration of the note for the corresponding beat/onset points. Since beat/onset points near the start of the song have shorter duration (P_j), initial iterative estimations for the note length have higher variation. For example in Fig. 6, beat/onset point P_1 is closer to start of the song and from the Eq. (1) and first estimation of note length X_1, we compute NF_1. Eq. (2) and (3) are useful in limiting the errors in computed NF under one frame. When X_1 is inaccurate and also P_1 is short then the errors in computed number of frames NF_1 in Eq. (1) have higher effects in the next estimated note length in Eq. (4). However with distant beat/onset points, i.e Pj is longer and NF_j is high and more accurate, then the estimated note lengths tend to converge.

3.2. Annotation of music regions

Pure vocal (PV), pure instrumental (PI), instrumental mixed vocal (IMV) and silence (S) are the regions that can commonly be seen in a music signals (Third layer of the music structure pyramid in Fig. 1). PV regions in the music only have signals generated from the vocal tract. Note that the lyrics of songs would improve the music region annotation. We use lyrics text files and employ subjects who understand the singing language to accurately stamp the timing of the region boundaries. We obtain lyrics of the songs from the Web. Based on the found lyrics, which are often separated into different musical phrases, we attempt to reorganize these lyrics and further separate them into different lines based on their vocal region continuity. Subsequently, vocal humming, for example *hmm, aah*, which are usually not included in the published lyrics, is also aligned with the vocals. Common types of song structure tagging are then used to identify a block of lyrics (e.g. Intro, Verse, Chorus, Bridge, Middle-eighth, Outro, and Instrumental)

Based on the music knowledge explained in Fig. 2, the duration of musical phrases can be measured by the number of musical notes. Since we have already calculated the note length in section 3.2, we use this information to improve the listening test of time stamping of music regions. In our annotation we assume the tempo of the song doesn't change. Since music signals are digitized at non-linear sampling rate (usually 44.1 kHz for CD quality), it's usually difficult to find the exact boundaries of vocal-instrumental regions. And also due to the effects of subject's concentration, hearing sensitivity and music experiences, position markings may vary from the actual boundary positions of the region. We further propose a 4-step process to improve the time stamps of music regions.

Step 1: Subject within his/her listening capacity marks the boundary point (start or end) of the region. For example, let's assume P_j and P_{j+n} in Fig. 6 are the start and the end time assigned in the listening process for the k^{th} pure vocal (PV) region. Let the note length be X. Then we estimate the number of frames for start and end time $\overline{NFvs}(k)$ and $\overline{NFve}(k)$ in Equation 5.

$$\overline{NFvs}(k) = \frac{P_j}{X} \quad and \quad \overline{NFve}(k) = \frac{P_{j+n}}{X} \tag{5}$$

It is empirically found that in popular songs, musical phrases are aligned with eighth or smaller note. Therefore at the beginning of the annotation we set the note length to eighth note.

Step 2: As the resulting $\overline{NFvs}(k)$ is usually an integer multiple of note length, we further measure the difference between $\overline{NFvs}(k)$ and round up $\overline{NFvs}(k)$ in order to refine the $\overline{NFvs}(k)$.

$$DFN = \left| \overline{NFvs}(k) \ - \ round\left(\overline{NFvs}(k)\right) \right| \tag{6}$$

IF (0.35 < DFN < 0.5)

IF (Note length > Thirty-second note)

Reduce the note length to next smaller one (e.g. Eighth to Sixteenth or Sixteenth to thirty-second note levels) and go to step

1 to update the previously calculated region boundaries based on new smaller note length frames.

ELSE

Minimum note resolution is considered as thirty-second note. Therefore there is no further note length adjustment. Go to step 3.

IF (DFN < 3.5)

Then do not alter the note length. Go to step3

Step 3: Re-estimate the number of frames $NFvs(k)$ and the time stamp for start position of k^{th} PV region $Tvs(k)$ respectively,

$$NFvs(k) \quad = \text{round}\left(\overline{NFvs}(k)\right) \tag{7}$$

$$Tvs(k) = NFvs(k) \times X \tag{8}$$

Similar sequence of steps is followed for more accurate estimation of end time $Tve(k)$ and end frame $NFve(k)$ of k^{th} PV region.

Step 4: Repeat Step 1-3 for annotating the next region boundaries.

Fig. 8 shows a section of an annotated song. Thirty-second note length resolution is used for the time stamp of music regions. Start-time and end-time of music regions found in the initial subjective listening tests are shown under STT and EDT columns respectively. Accurate start-frame and end-frame of the regions are shown under STF and EDF columns respectively. According to Equation 8 accurate end-time of the instrumental Intro region (PI-Intro) is 1263.06818182 ms (i.e. 135×93.56060606).

It can be seen in the Fig. 8 that end-time of PI has as high as 8 decimal points caused by multiplying frame numbers with the note length which has 8 decimal places. As explained earlier, music region boundaries can be measured as multiples of music notes. Thus it is necessary to have a better estimation for the note-length to reduce errors at boundaries when the number of frames for the boundary increases. Thus it becomes essential to have more decimal places in the estimated length for the note.

Artist: MLTR
Song: The Actor
Demisemiquaver Beat: 93.56060606 ms

STT Starting time
STF Starting frame
EDT Ending time
EDF Ending frame

Instrumental Mixed Vocal				Pure Vocal	Instrumental				Silence				Lyrics
STT	EDT	STF	EDF		STT	EDT	STF	EDF	STT	EDD	STF	EDF	
									0.000	0.250	1	3	
					0.250	12.598	4	135					<Intro>
12.598	16.715	136	179		16.715	18.586	180	199					<V1>He takes you out and he takes you up
18.586	21.580	200	231		21.580	24.573	232	263					'Cause he can show you so much
24.573	28.690	264	307		28.690	30.561	308	327					I go to bed and tomorrow again
30.561	32.807	328	351										There's a lot of
32.807	34.678	352	371		34.678	36.549	372	391					work to be done
36.549	40.291	392	431		40.291	42.537	432	455					He gives you gold and he'll promise you
42.537	45.531	456	487		45.531	48.525	488	519					The whole world will be yours
48.525	52.267	520	559		52.267	54.512	560	583					I just can tell you I love you so
54.512	55.636	584	595		55.636	56.384	596	603					Even though
56.384	57.474	604	614		57.474	57.833	615	618					my odds
57.833	59.004	619	631		59.004	60.500	632	647					are low
60.500	63.081	648	674		63.081	63.499	675	679					<C1>I'm not an actor I'm not
63.499	64.617	680	691		64.617	65.740	692	703					a star
65.740	67.981	704	727		67.981	68.364	728	731					And I don't even have
68.364	69.856	732	747		69.856	72.850	748	779					my own car
72.850	75.248	780	804		75.248	75.521	805	807					But I'm hoping so much
75.521	76.967	808	823		76.967	78.464	824	839					you'll stay
78.464	80.026	840	855		80.026	80.345	856	859					That you will love
80.345	81.832	860	875		81.832	84.452	876	903					me anyway
84.452	88.569	904	947		88.569	90.440	948	967					<V2>The dirty games and the neon shows
90.440	93.433	968	999		93.433	96.427	1000	1031					This is the world he knows

***STT and EDT are found in the listening test. STF and EDF are computed in the annotation process**

Fig. 8. Section of manually annotated vocal and instrumental boundaries of the first few phrases of the song "The Actor" by MLTR. The frame length is equal to the thirty-second note (93.56060606 ms).

3.3. Annotation of song structure

We follow these assumptions while annotating the semantic regions in a popular song.

- Verse and Choruses are usually 8 or 16 bars, but can be 4 bars.
- All the Verses only share similar melody but different vocals.
- All the Choruses have similar vocals and melody.
- The melody of the Verse and Chorus can be similar or different.
- The bridge is less than 8 bars and can be instrumental
- The Middle-eighth is usually 8 or 16 bars and has a different key from the original song. Middle-eighth regions are identified by detecting the region(s) which have a different key from the main key in the intensive listening test.
- INST is usually 8 or 16 bar long instrumental section which appears neither begin nor the end of the song.

Fig. 9 explains the general overview of the components of the song structure. Usually Verse, Chorus and Middle-eighth start with vocals and may end with either vocals or instrumental section. In Fig. 8, we have shown the annotation of the Intro, Verse 1, and Chorus 1, and the start of the Verse 2. We set the tolerance of ± 2 bars for judging the duration of Verse or Chorus.

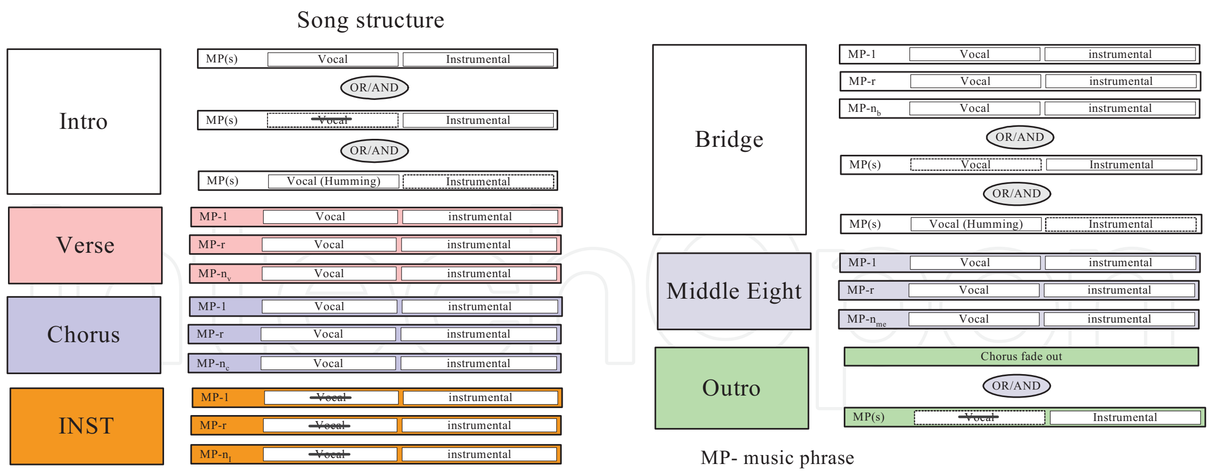


Fig. 9. Visualization of the components in a popular song.

4. Statistical Analysis of the Music Information

We conduct statistical analysis over a database of 420 songs, 120 English songs and 100 songs of each Chinese, Indonesian and German languages. Table 1 summarizes the database. We then carry out listening tests to extract the structural information. An average of 3 hours of intensive listening is required all the annotations per song. The following subsections pictorially discuss the statistics.

4.1. Time information statistics

Tempo describes the speed of the information flow in the music. Fig. 10-(a) discusses the average (Avg) and standard deviation (Std) of tempos based on gender male/ female and total for different languages. Avg and Std of all the songs (i.e. 420 songs) are shown in Fig. 10-(b). The standard deviation (Std) of tempos, in other words the fluctuation of the tempos tells us how dynamic the songs in that cluster are.

It can be seen in Fig. 10-(a) that for all the languages, Avg and Std of the tempos in the male song cluster are higher than they are in the female song cluster. In our song collection, Indonesian male songs have the highest Avg tempo with respect to other languages. As shown in Fig. 10-(b), Avg tempo of male songs is 15 BPM higher than the Avg tempo of female songs and Std of female songs is 5 BPM lower than that of male songs. Fig. 11 details the tempo statistics in histograms.

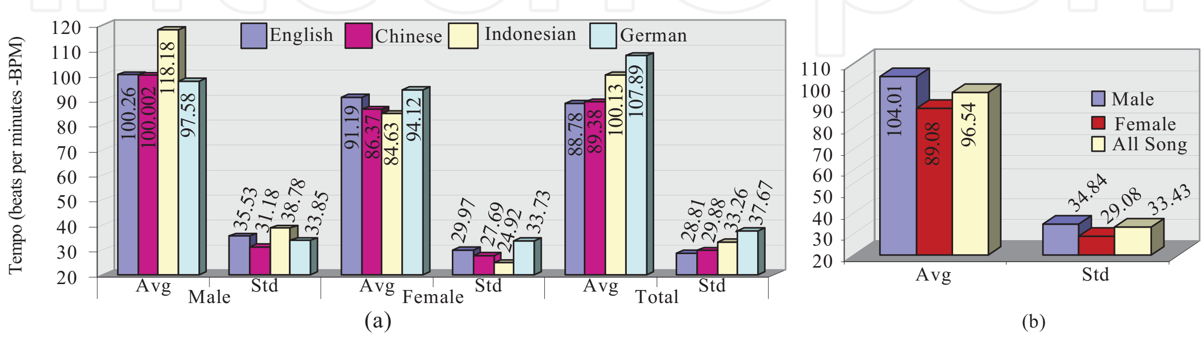


Fig. 10. Tempo statistics of the songs

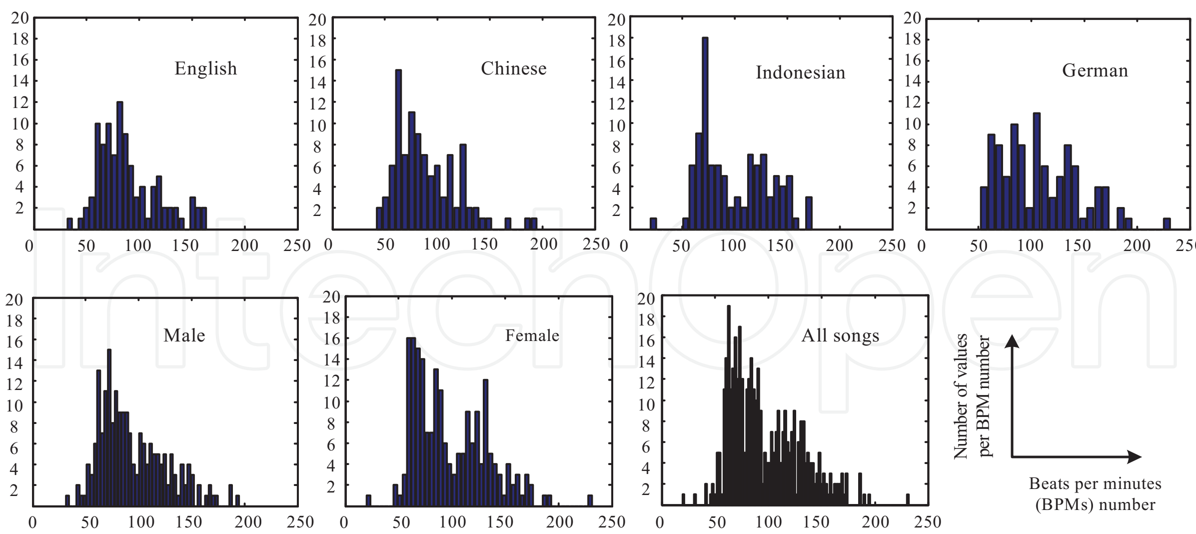


Fig. 11. Tempo statistic histograms

4.2. Music region statistics

Equation (9) describes the distribution of content with respect to region types for songs in the test database. We have $k = 1,2,3,4$ to represent PV, PI, IMV or S regions respectively. Let $NF(k)$ be the total number of frames belonging to region type k and NF_{all} be the total number of frames in a song or a collection of songs. We have

$$D_k = \frac{NF(k)}{NF_{all}} \tag{9}$$

Fig. 12 shows the average content distribution D_k in our database. According to Fig. 12-(a), pure vocal regions in popular music are rare. Silence regions mostly appear at the beginning and at the ending of a song, and constitute a small percentage in the distribution as well. Fig. 12-(b) explains the content distributions by genders and languages. The deviation of IMV and PV region contents is around 10% across the genders and languages. However the deviation is around 2% per song for silence regions. Fig. 13 explains the region content distributions in histograms.

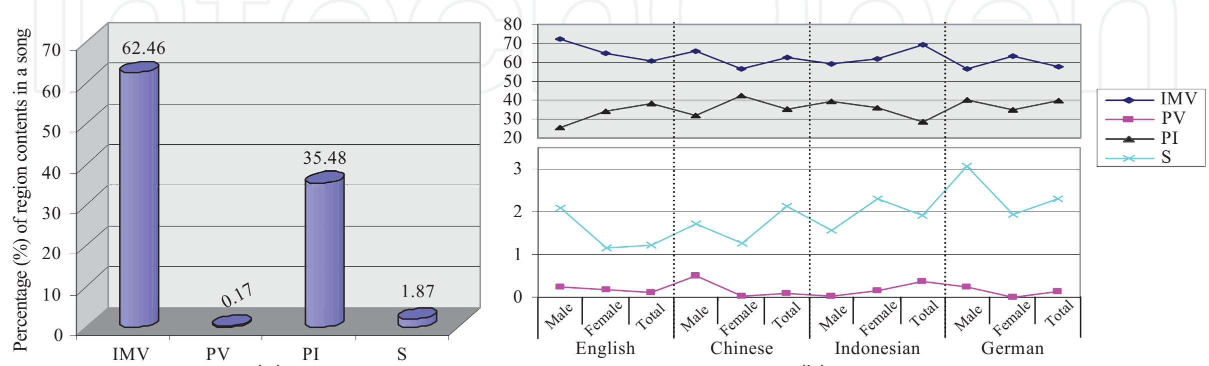


Fig. 12. Distribution of region contents over 420 songs

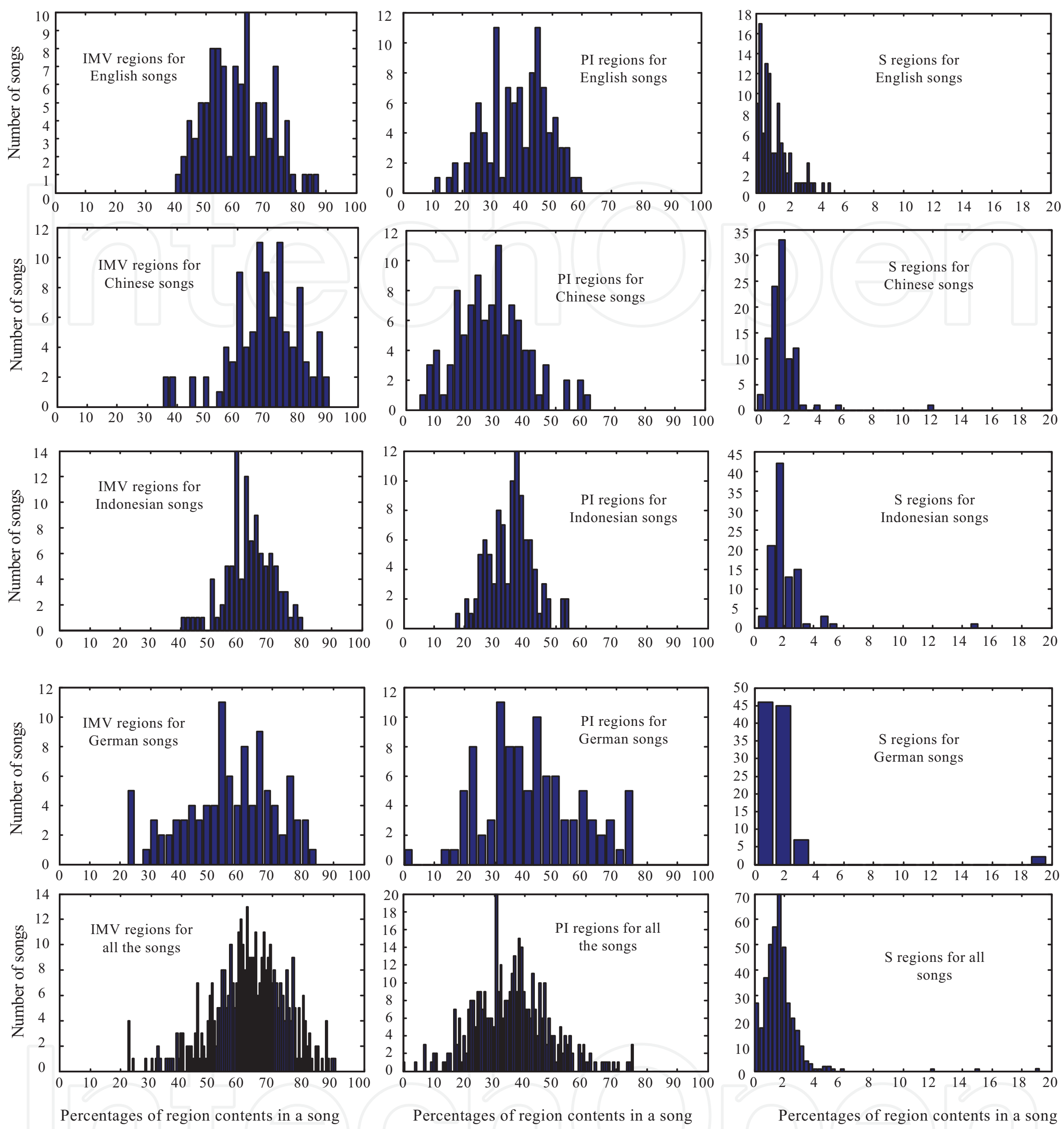


Fig. 13. Histograms of region content distributions

4.3. Song structure statistics

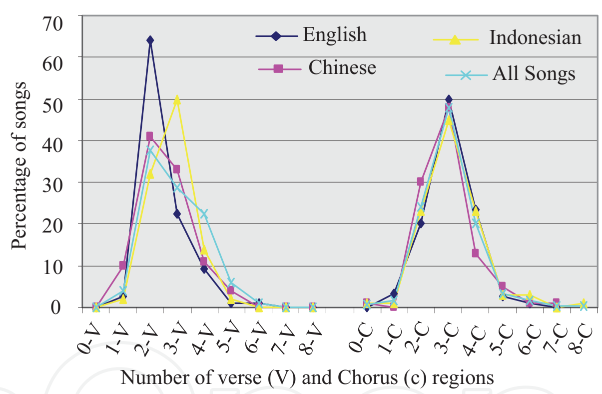
General knowledge about popular song structures is explained in section 2.4. In this section, important statistics about the components of the song structures are explained in point 1 to 9. Point 10 and 11 discuss the statistics of popular song structures. The song structure statistics are calculated using English, Chinese and Indonesian songs.

Total Songs	English 120	Chinese 100	Indonesians 100	All Songs 320
(1) How many songs have Intro?	95.83%	97.00%	99.00%	97.19%
(a) How many songs have instrumental Intros?	80.00%	74.00%	67.00%	74.06%
(b) How many songs have vocal mixed instrumental Intros?	15.83%	14.00%	32.00%	20.31%
(2) If no Intro,	4.17%	2.00%	1.00%	2.50%
(a)how many songs start with Verse?	4.17%	1.00%	1.00%	2.19%
(b) how many songs start with Chorus?	0.00%	1.00%	0.00%	0.31%
(3) How many songs have instrumental Outros?	13.33%	45.00%	39.00%	31.25%
(a) How many songs have chorus melody in the Outro?	0.83%	0.00%	0.00%	0.31%
(b) How many songs have verse melody in the Outro?	0.00%	0.00%	0.00%	0.00%
(4) How many songs have vocal mixed instrumental Outros?	86.67%	45.00%	59.00%	65.00%
(a) Howmany songs have fading choruse vocals and melody?	38.33%	8.00%	4.00%	18.13%
(b) Howmany songs have fading verses vocals and melody?	3.33%	0.00%	0.00%	1.25%
(5) How many songs have middle eighth?	53.33%	15.00%	2.00%	25.31%
(6) How many songs have INST regions?	51.67%	82.00%	65.00%	65.31%

	English	Chinese	Indonesian	All Songs
INST-0	**48.33%**	18.00%	35.00%	34.69%
INST-1	**42.50%**	**65.00%**	**51.00%**	**52.19%**
INST-2	9.17%	17.00%	12.00%	12.50%
INST-3			2.00%	0.63%

(7) Percentages of songs that have number of verses (n-V) and number of choruses (n-C)

No of regions	English		Chinese		Indonesian		All songs	
	Verse	Chorus	Verse	Chorus	Verse	Chorus	Verse	Chorus
0				1.00		1.00		0.63
1	2.50	3.33	10.00		2.00	1.00	4.06	1.56
2	64.17	20.00	41.00	30.00	32.00	23.00	37.50	24.06
3	22.50	50.00	33.00	48.00	50.00	45.00	28.75	47.81
4	9.17	23.33	11.00	13.00	14.00	23.00	22.50	20.00
5	0.83	2.50	4.00	5.00	2.00	3.00	5.94	3.44
6	0.83	0.83		1.00		3.00	0.94	1.56
7				1.00				0.31
8						1.00		0.31



(8) Percentage of songs have verse - chorus combinations

English songs (Number of Verses × Number of choruses)

Number of Verses	1	2	3	4	5	6	7	8
1		2.50						
2	0.83	7.50	35.83	18.33	1.67			
3	1.67	6.67	9.17	4.17	0.83			
4	0.83	2.50	5.00	0.83				
5		0.83						
6						0.83		
7								
8								

Chinese songs (Number of Verses × Number of choruses)

Number of Verses	0	1	2	3	4	5	6	7	8
1			5.00	4.00		1.00			
2			13.00	18.00	8.00	2.00		1.00	
3			8.00	18.00	5.00	1.00	1.00		
4	1.00		4.00	5.00		1.00			
5			1.00	3.00					
6									
7									
8									

Indonesian Songs (Number of Verses × Number of choruses)

Number of Verses	0	1	2	3	4	5	6	7	8
1			1.00	1.00					
2	1.00	1.00	6.00	15.00	7.00	1.00			1.00
3			11.00	25.00	10.00	1.00	3.00		
4			3.00	4.00	6.00	1.00			
5			2.00						
6									
7									
8									

All the Songs (Number of Verses × Number of choruses)

Number of Verses	0	1	2	3	4	5	6	7	8
1			2.81	1.56		0.31			
2	0.31	0.63	8.75	23.75	11.56	1.56		0.31	0.31
3		0.63	8.44	16.88	6.25	0.94	1.25		
4	0.31	0.31	3.13	4.69	2.19	0.63			
5			1.25	0.94					
6							0.31		
7									
8									

(9) length of verse and chorus

For English Songs

Length of Verse in Bars	Length of Chorus in Bars: 4	8	16	Others
4	2%	5%	0%	0%
8	2%	51%	9%	5%
16	1%	6%	12%	2%
Others	0%	5%	1%	1%

For Chinese Songs

Length of Verse in Bars	Length of Chorus in Bars: 4	8	16	Others
4	4%	5%	2%	4%
8	1%	37%	18%	4%
16	0%	5%	9%	1%
Others	0%	4%	3%	3%

For Indonesian Songs

Length of Verse in Bars	Length of Chorus in Bars: 4	8	16	Others
4	1%	1%	2%	1%
8	3%	35%	24%	2%
16	0%	8%	13%	4%
Others	0%	3%	1%	2%

For All Songs

Length of Verse in Bars	Length of Chorus in Bars: 4	8	16	Others
4	2%	4%	1%	2%
8	2%	42%	17%	4%
16	0%	6%	11%	2%
Others	0%	4%	2%	2%

Song structures

	English	Chinese	Indonesians	All
(10) How many songs have V-C-V-C repetition?	58%	19%	27%	36%
a. how many songs have mid-eighth?	23%	3%	1%	10%
b. how many songs have inst?	26%	9%	17%	18%
(11) How many songs have V-V-C-V-C repetition?	10%	9%	50%	22%
a. how many songs have mid-eighth?	5%	3%	1%	3%
b. how many songs have inst?	3%	4%	33%	13%

4.4. Summary of song structure statistics

- It is found that over 95% of the English, Chinese and Indonesian songs have an introduction (i.e. Intro) and over 65% of them have instrumental Intros.
- Over 90% of songs have either instrumental mixed vocals or an instrumental Outro. Around 38% of English songs have fading Choruses (vocal + melody) as Outro.

- Middle-eighth is more commonly appear in English songs than Chinese and Indonesian songs.
- Over 50% of Chinese and Indonesian songs have an INST region and around half of the English songs may not have an INST region.
- Over 50% of the English songs have Middle-eighth regions but there these regions are rare in Chinese and Indonesian songs.
- Majority of the songs have 2~3 Verses and 2~4 Choruses.
- In many songs, the chorus and verse lengths are of 4, 8, or 16 bars. Most songs have the same chorus and verse length, i.e. 8 bars.
- Over 70% of the English and Indonesian songs have V-C-V-C and V-V-C-V-C song structures whereas it is around 30% for Chinese songs. (V and C are abbreviation of Verse and Chorus respectively.)

5. Discussion

This chapter reports a statistical analysis of the music information in popular English, Chinese, Indonesian and German songs. Intensive listening tests were carried out by subjects who have good knowledge of musicology and the language of the vocals, to determine the tempo, time indexing of music regions and song structures.

The reported statistics about the music information can be used as prior knowledge in formulating constraints for music information extraction systems. For example, for setting up the window size to detect onsets, beats in the rhythm extractor, to form heuristic rules to detect popular song structures. Sound of music is a combination of creative imaginations of the composer, singer and orchestra, which is diversified along many directions such as ethnicity, culture, and geographical locations. Therefore, song structures can differ from one composer to another. The current database that we used consists of 420 songs from four languages. Although the statistics may not be enough to draw general conclusions about song structures, they can be considered as an indication of common practice in popular song composition.

6. Acknowledgement

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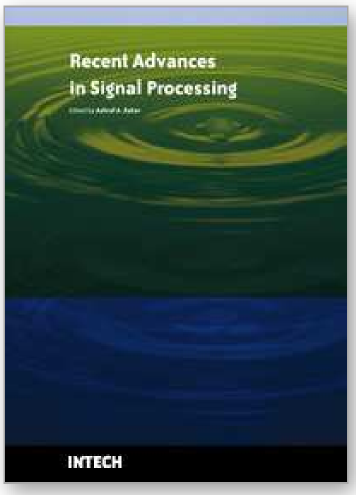
	Album name	English songs (Female vocals)									
1	Celine Dion (Falling into you)	Falling Into You	Make You Happy	Seduces Me	All By Myself	Dreaming Of You	I Love You	If That's What It Takes	I Don't Know	14-Your Light	Call The Man
2	Dido (Life for rent)	White Flag	Stoned	Life For Rent	Mary's In Indian	See You When You Are 40	Don't Leave Home	Who Makes You Feel	Sand In My Shoes	Do You Have A Little Time	This Land Is Mine
3	Faith Hill (Love will always win)	This kiss	Me	Love Aren't Like That	Piece Of My Heart	The Secret Of Life	Better Days	I Love You	The Hard Way	Somebody Stand By Me	Let Me Let Go (Bonus Track)
4	Mariah Carey (Greatest HIts)	Vision of love	Love takes time	I don't wanna cry	Cant let go	Hero	Without you	Any time you need a friend	All I have ever wanted	I still believe	My all
5	Shania Twain (Come on Over)	From this Moment On	The woman in me	Honey I am Home	Don't be stupid (You know I love you)	Love Gets me every time	Still the one	Black eyes blue tears	When	Come on over	Im holdin on to love to save my life
	Album name	English songs (Male vocals)									
1	Ben Jelen (Give it all away)	Come On	Rocks	She'll Hear You	Give It Away	Every Step	Christine	Wicked Little Town	Falling Down	Stay	Criminal
2	Bryan Adams (On a Day Like Today)	How do u feel tonight	C'mon C'mon C'mon	On a day like today	Fearless	I am a Liar	When you are gone	Before the night is over	Where the angles fear to treads	Lie to me	Cloud No-9
3	Elton John (Greatest Hits 1970 - 2002)	Your Song	Daniel	Candle in the Wind	I Guess Thats Why They Call It the Blues	Nikita	Sacrifice	Can You Feel the Love Tonight	Circle of Life	Made in England	I Want Love
4	Michael Bolton (Vintage)	The Very Thought of You	All the Way	A Kiss to Build a Dream On	If I Could	At Last	When I Fall in Love	You Don't Know Me	mile	Daddys Little Girl	What Are You Doing the Rest of Your Life
5	Michael Learns to Rock - MLTR (Paint My Love)	25 Minutes	Breaking My Heart	Complicated Heart	How Many Hours	Paint My Love	Sleeping Child	Somday	That's Why (You Go Away)	The Actor	Wild Women
6	Richard Marx (Greatest Hits)	Slipping Away	Endless summer nights	Don't mean nothing	Children of the Night	Should have known better	Hazard	Angelia	Hold on to the nights	Take this heart	Right here waiting
7	West life (West life)	Change the World	Flying without wings	Fool Again	I Don't Wanna Fight	If I let you go	Miss You	My Love	Seasons in the Sun	Somebody needs you	Swear it Again
	Album name	Chinese songs (Female vocals)									
1	FIR□ Fly□ □□□□□□	Fly Away	Lydia	Liu Lang Zhe Zhi Ge	Wo Men De Ai	Guang Mang	Ni De Wei Xiao	Ta Luo Pai	Hou Le Yuan	Revolution	You Make Me Want To Fall In Love
2	Liang jinru□ FISH- Lian ai de li liang□ □□□□□□□□□□	Bu Xiang Shui	Ru Guo You Yi Tian	Cai Hong	Ai Ni Bu Shi Liang San Tian	Zui Xiang Huan You De Shi Jie	Dui Bu Qi Wo Ai Ni	Zhi Neng Bao Zhe Ni	Di San Zhe	Zuo Tian	Ming Tian De Wei Xiao
3	Rene Liu (Full Bloom) □□□	Bang Wan	Cheng Quan	Dian Liang Ju Zi Shu	Dui Mian Nan Sheng De Fang Jian	Mi Mi	Nian Hua	Wang Le	Wo Ceng Ai Guo	Yi Wang De Cheng Shi	Yong Gan
4	Pei Ni□ SoPenny-hao) □□□□□	Fang Kong Dong	Xin De Rui La	Bu Xiang	Xi Guan Zhe Yang	Tou Qi	Ri Qi	Zen Yang	Ni Yao De Ai	Hao Gan Jue	Ai Guo
5	Zhao Wei□ Vicky-Piao□ □□□□□	Bian Le	Zhe Yi Ke Wo Xiang Xin Ni Shuo Wi Ai Ni	Jian Jian	Wu Jin De Sha Shi Bi Ya	Yi Zhi Xia Yu De Xing Qi Tian	Biao Qing Dong Zuo Yan Yu	Zhuang Tai	Sheng Ming Li De Zhe Yi Tian	Shi Yi Yue	Tian Shi Zhi Ming

Table 1. List of songs, singers and their albums (ten songs from each album) used for the test

	Album name	Chinese songs (Male vocals)									
1	Zhou Jie Lun (Qi Li Xiang- JAY)	Wo De Di Pan	Qi Li Xiang	Jie Kou	Wai Po	Jiang Jun	Ge Qian	Luan Wu Chun Qiu	Kun Shou Zhi Dou	Yuan You Hui	Zhi Zhan Zhi Shang
2	A du (Tianhei)	Andy	Li bie	Ni heng hao	Right here waiting	Si ye	Ta yi ding	Tian Hei	TianTian	Wu fa zu dang	Yi ge ren zhu
3	Zhou Chuan Xiong (Transfer)	Wang Ji	Chu Mai	Ji Mo Hong Zha	You Xi Ai Qing	Xin Jie	Ji Shi Ben	Pi Jiu Pao Pao	Xin Xue Lai Chao	Mo Ban Che	Shi Jian
4	Dao Lang	Ka Shi Ge Er Hu Yang	Guan Yu Er Dao Qiao	Wu Yi Ye Shi De Xiong Di	Zhi You Ai De Le Si Neng Kan Jian	Shou Zai Ling Chen Liang Dian De Shang Xin Show Bar	Da Yan Jing	Ya Ka Xi	Zai Jian Wu Lu Mu Qi	Da Qi Shou Gu Chang Qi Ge	Bing Shan Shang De Xue Lian
5	Ou De Yang (Ocean)	Xing Fu Che Zhan	Xiu Xiu Xiu	Gu Dan Bei Ban Qiu	Lang Man Qun Dao	Li Qi	Ma Ya Jin Zi Ta	Yi Ren Yi Ban	Peng You Zui Jin Hao Ma	Liang Jian Shi	Shang Xuan Yue
	Album name	Indonesian songs (Female vocals)									
1	Rosa	Kembali	Aku Bukan Untukmu	Bicara Pada Bintang	Pudar	Cintai Aku	Akankah Bisa	Biar	Pujaan Hati	Wanita Yang Kau Pilih	Pudar Soundtrack Version
2	Nina	Aku Bahagia	Kau Datang	Karena Ku Tak Bisa	Di Sore Nanti	Yang Terbaik	Baca Hatiku	Empat Musim	Kembali Padamu	Percuma	Tak Menjauh
3	Audy	Pertama Kali	Temui Aku	Kita Takkan Bersatu	Kutak Bisa Memberi	Silang Hati	Tiada Akhir	Lagu Sendu	Setelah Kau Pergi	Kisah Yang Sama	Lebih Baik Darimu
4	Andien	Denganmu Sahabatku	Milikmu Selalu	Ku Akan Menanti	Menyambut Kasihmu	Kucemburu	Menyanyi Menari	Satu Dua dan Tiga	Gemintang	Untukmu	Cerita Lama
5	Tere	Pencuri Hati	Dosa Termanis	Cukup Bagiku	Pasangan Sepadan	Pertanyaan Hati	Panggung Sandiwara	Kala Cinta Bicara	Begitu Berharga	Apa Adanya	Bukan Jalan Kita
	Album name	Indonesian songs (Male vocals)									
1	Naif (City of Joy)	Gula Gula	Benci Untuk Mencinta	Pujaan Hati	Takkan Pernah Melupakan mu	Nanar	Senyum Yang Hilang	Akulah Pasanganm u	Uang	Tak Mampu Mendua	Pagi
2	Mike	Semua Untuk Cinta	Kembali	Besar	Terbaik	Yang Hitam	Cinta Kan Membawa mu Kembali	Sempurnala h Mimpiku	Cinta Tak Bertuan	Persembah an	Arti Kesetiaan
3	Peterpan	Tak Bisakah	Jauh Mimpiku	Membebani ku	Menunggu Pagi	Kukatakan Dengan Indah	Sahabat	Aku & Bintang	Mungkin Nanti	Di Belakangk u	Langit Tak Mendenga r
4	Kerispatih	Maafkan Aku	Hanya Kamu Yang Bisa	Lagu Rindu	Berpisah	Memang Ini Jalanku	Cuma Manusia	Cinta Putih	Pertama dan Terakhir	Janji Kita	Lupakan Aku
5	Ello	Pergi Untuk Kembali	Mungkin Mereka Bilang	Terbaik	Dirimu	Kekasih Khayalan	Kau (feat. Glenn Fredly)	Sudahlah	Sampaikan Padanya	Kau Bukan Kekasihku	Kisah Kita T'lah Usai
	Album name	German songs (Female vocals)									
1	Wir Sind Helden	Wenn es passiert	Echolot	Von hier an blind	Ein Elefant fuer dich	Darf ich das behalten	Wuetend genug	Zieh dir was an	Nur ein Wort	Ich werde mein Leben lang	Bist du nicht muede
2	Silbermond	Machs dir selbst	Durch die Nacht	Du und ich	An dich	Passend gemacht	Symphonie	1000 Fragen	Letzte Bahn	Ohne dich	Wissen was wird
3	Nena	Willst du mit mir gehn	Lass mich	Und jetzt steh ich hier und warte	Liebe ist	Ich komm mit dir	Immer weiter	Ohne Liebe bin ich nichts	Vitamine	Wir fliegen	Neues Land
4	Juli	Warum	Sterne	Geile zeit	Tage wie dieser	Traenensch wer	Perfekte Welle	Regen und Meer	November	Anders	Ich Verschwin de
5	Annett Louisan	Das grosse Erwachsen	Thorsten Schmidt	Chancenlos	Gedacht ich sage nein	Eve	Laueft alles perfekt	Wo ist das Problem	Er gehoerte mal mir	Die Loesung	Der den ich will
	Album name	German songs (Male vocals)									
1	Ben	Herz aus Glas	Da fuer mich	Die Reise	Gesegnet seist Du	Irgendwo	Du bist mein Herz	Zurueck zu mir	Warum soll ich gehn	Sie bringt die Sonne mit	Es wird Zeit
2	Echt	Wie Geht Es Dir So	Meisterwer k	In Dieser Gegend	Wahrheit	Du Bist Nicht Echt	Haar	Wie Ein Maedchen	Nachbarsch aft	Kurz Nach Dem Aufstehen	An Deiner Seite
3	Mensch	Mensch	Neuland	Der Weg	Viertel Vor	Lache Wenn es nicht zum weinen reicht	Unbewohnt	Dort und hier	Blick zurueck	Kein Pokal	Zum Meer
4	Soehne Mannheims	Wenn Du Schlaefst	Vielleicht	Von Anfang An Dabei	Koenig Der Koenige	Traurige Lieder	Im Interesse Unserer Gemeinsch aft	Ich Geh Mit Dir	Dein Leben	Und Wenn Ein Lied	Vatter unser
5	Tocotronic	Freiburg	Du Bist Ganz Schoen Bedient	So Jung Kommen Wir Nicht Mehr Zusammen	Let There Be Rock	Jackpot	This Boy is Tocotronic	Aber Hier Leben Nein Danke	Gegen Den Strich	Pure vernunft darf niemals siegen	Pure vernunft darf niemals siegen



Recent Advances in Signal Processing
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The signal processing task is a very critical issue in the majority of new technological inventions and challenges in a variety of applications in both science and engineering fields. Classical signal processing techniques have largely worked with mathematical models that are linear, local, stationary, and Gaussian. They have always favored closed-form tractability over real-world accuracy. These constraints were imposed by the lack of powerful computing tools. During the last few decades, signal processing theories, developments, and applications have matured rapidly and now include tools from many areas of mathematics, computer science, physics, and engineering. This book is targeted primarily toward both students and researchers who want to be exposed to a wide variety of signal processing techniques and algorithms. It includes 27 chapters that can be categorized into five different areas depending on the application at hand. These five categories are ordered to address image processing, speech processing, communication systems, time-series analysis, and educational packages respectively. The book has the advantage of providing a collection of applications that are completely independent and self-contained; thus, the interested reader can choose any chapter and skip to another without losing continuity.

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