# DEVELOPMENT OF AN AUTOMATIC MUSIC SELECTION SYSTEM BASED ON RUNNER'S STEP FREQUENCY

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## ABSTRACT

This paper presents an automatic music selection system based on runner's step frequency. Recent development of portable music players like iPod has increased the number of those who listen to music while exercising. However, few systems which connect exercises with music selection have been developed. We propose a system that automatically selects music suitable for user's running exercises. Although many parameters can be taken into account, as a first step we focus on runner's step frequency. This system selects music with tempo suitable for runner's step frequency and when runner's step frequency changes, it executes another music selection. The system consists of three modules: step frequency estimation, music selection, and music playing. In the first module, runner's step frequency is estimated from data derived from an acceleration sensor. In the second module, appropriate music is selected based on the estimated step frequency. In the third module, the selected music is played until runner's step frequency changes. In the experiment, subjects ran on a running machine at different paces listening to the music selected by the proposed system. Experimental results show that the system can estimate runner's SPM accurately and on the basis of the estimated SPM it can select music appropriate for users' exercises with more than 85.0% accuracy, and makes running exercises more pleasing.

## 1 INTRODUCTION

Recently, people can collect massive volumes of digital music data easily due to efficient audio compression techniques like MP3 and online music distribution services. Portable music players like iPod have enabled people to listen to music while doing other things: driving, browsing, or sporting. These circumstances have brought great demand for a system that selects music data suitable for their listening environments from among massive volumes of music data.

There are some commercial products concerning automatic music selection. Portable music players for exercising such as NW-S203F [13] and Nike+iPod Sport Kit [2] have attracted public attention. NW-S203F has an acceleration sensor, with which it can count steps, measure distance traveled, and track calories burned. Nike+iPod Sport Kit consists of a wireless sensor attached to a shoe and a receiver plugged into a portable music player. The sensor sends information such as pace, distance, and calories burned to the receiver, and the music player can store and display this data. These products function not only as portable music players but also as exercise equipment. However, these functions are independent and the information which is obtained while exercising does not influence music selection.

There are also some previous studies on automatic music selection systems using user's information. MPTrain [9, 10, 11] is designed as a mobile and personal system (hardware and software) that users wear while exercising such as walking, jogging or running. MPTrain's hardware includes a set of physiological sensors wirelessly connected to a mobile phone carried by the user. MPTrain does not take any action until about 10 seconds before the end of the current song. It then determines whether the user needs to increase, decrease or keep the running pace, by comparing the user's current heart-rate with the desired heart-rate from the desired workout for that day. Once it has determined the action to take, it searches the user's digital music library (DML) for the optimal song to play. The context-aware mobile music player PersonalSoundtrack described in [4] works with its owner's library to select music in real-time based on a taxonomy of attributes and contextual information derived from an accelerometer connected wirelessly to a laptop carried under the arm. On the basis of user feedback and analysis, a hand-held device is implemented for testing in less constrained mobile scenarios.

These systems select music automatically based on user's listening environments, however, these studies do not investigate in detail how the musical tempo influences user's pleasingness, nor do an objective evaluation to show how accurately their system can estimate runner's step frequency.

In this paper, we propose an automatic music selection system that interacts with user's running exercises. Many parameters can be taken into account, but as a first step we focus on runner's step frequency. We conducted a preliminary experiment to investigate how actual musical tempo influences runner's pleasingness in the relation with his step frequency. On the basis of the result, we develop a system that automatically selects music with appropriate tempo based on runner's step frequency. This paper is structured as follows: in Section 2 we investigate how actual BPM influences user's pleasingness. In Section 3 we propose an automatic music selection system reflecting runner's step frequency. In Section 4 we present experiments to evaluate the proposed system. Finally in Section 5 we offer concluding remarks and discuss future work.

## 2 PRELIMINARY EXPERIMENT

In this paper, the developed system which automatically selects music by tempo is described. Tempo is defined as speed at which a musical composition is played [12], and represented by BPM (Beat Per Minute). Some experiments have shown that musical tempo has a great effect on people in the areas of performance of track athletes [3] and on general spatial awareness, arousal and mood [7]. This previous paper [1] studies the influence of the tempo of various pieces of music on SPM (Step Per Minute) of users running while listening to them. It concludes that there is no correlation between tempo and SPM, but there is significant correlation between tempo and subjective rating. These experiments imply that musical tempo is strongly connected with human perception.

In order to investigate how actual BPM influences user's pleasingness, we conducted a preliminary experiment. In the preliminary experiment, six subjects (university students) ran at constant step frequency (150 SPM) listening to two different kinds of music: one is calm and melodious and has a weak beat (Track1), while the other is rhythmical and has a strong beat (Track2). They were composed for the experiment, and BPM of each song was changed at each time :150±5, 10, 35, 40, 45, 70, and 80.

Figure 1 indicates the result of the experiment. Correlation coefficient between the difference between SPM and BPM and evaluated pleasingness of Track1 was -0.589 and that of Track2 was -0.634. This result leads us to the conclusion that people tend to feel pleased when BPM is near their SPM.

## 3 AUTOMATIC MUSIC SELECTION SYSTEM

### 3.1 Overview of the proposed system

In this section, we propose a system which selects music by BPM based on the result of the preliminary experiment. Figure 2 indicates an overview of the proposed system. The proposed system consists of three modules: step frequency estimation, music selection, and music playing. First, it estimates runner's step frequency based on data derived from an acceleration sensor (step frequency estimation module). Next, it selects music based on the estimated step frequency (music selection module). Finally, it plays the selected music (music playing module). We explain each module in detail in the following sections.

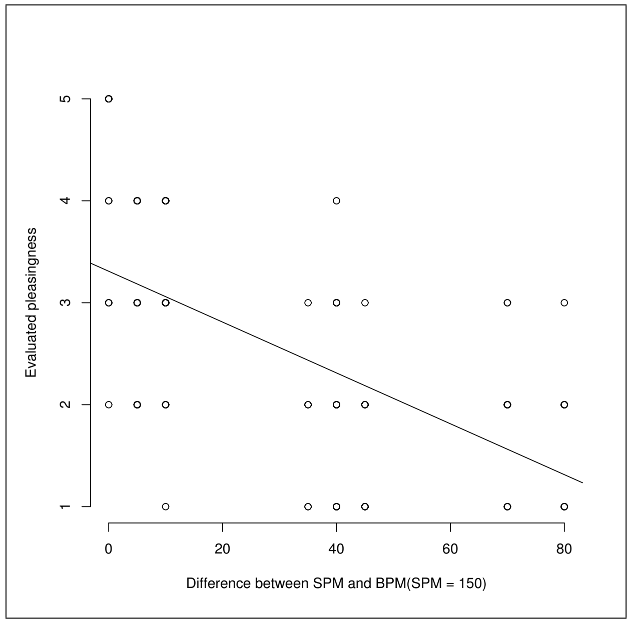


**Figure 1**. Evaluated pleasingness as a function of difference between SPM and BPM

### 3.2 Step Frequency Estimation Module

Our preliminary experimental results show that human step frequency ranges from 70 to 220 SPM. We set sampling frequency of an acceleration sensor at 100Hz, in order to detect steps even if the rate is 600 SPM. We assume that the user takes a step when the acceleration sensor indicates the maximum value. We can calculate an interval between two steps $\Delta t$ as Equation (1).

$$\Delta t = t_n - t_{n-1} \quad (1)$$

where $t_n$ is the time (sec) the user takes $n$ steps. We can estimate SPM as Equation (2).

$$\text{SPM} \simeq \frac{60}{\Delta t} \quad (2)$$

SPM is updated every time the acceleration sensor indicates the maximum value.

### 3.3 Music Selection Module

We assume BPM does not change throughout the entire piece and group pieces of music according to its BPM. Each group consists of pieces of music whose BPM are between $n$ and

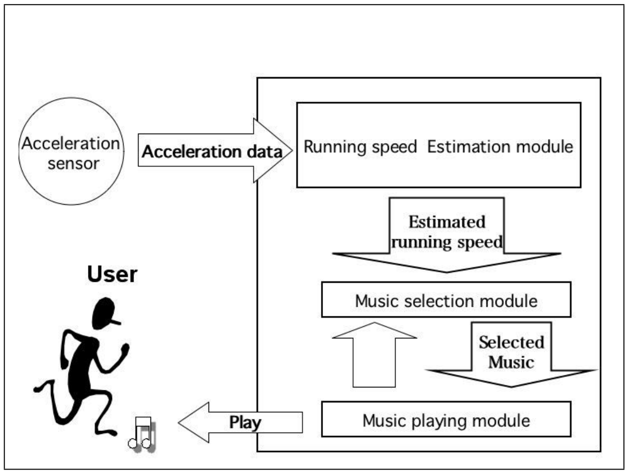


**Figure 2**. An overview of the proposed system

**Figure 3**. A mobile acceleration sensor:WAA-001

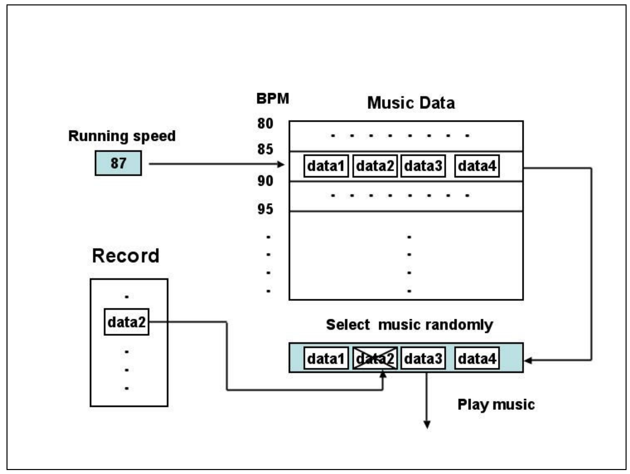


**Figure 4**. A description of the music selection module

$n+4$, which is labeled as $n$. Music selection module searches for the music group whose label $n$ is the closest in value to user's SPM and selects one piece of music at random from the group. The pieces of music selected by the system in the last ten selections are logged, and are not selected again to avoid repetition.

We give an example in Figure 4. The input (step frequency) to the music selection module is 87 and data1, data2, data3 and data4 are music data. In this case, data1, data2, data3 and data4 are candidates because they are included in the music group labeled as 85, which is the closest in value to 87. Data2 is not selected because it is in the record. The system selects one at random from data1, data3 and data4. In this example, data3 is selected and input into the music playing module.

### 3.4 Music Playing Module

In the music playing module, the music selected in the previous module is played. When runner's step frequency changes, the system executes another music selection using current SPM. This function enables the runner to always listen to music with tempo suitable for his step frequency without manual control. Let $P$ be the estimated SPM, $\overline{P}$ be the average of the last 10 $P$, $bNow$ be BPM of the playing music, $E$ be the allowable gap between BPM and SPM, $Count$ be a counter, and $uBound$ be upper bound of the times $P$ or $\overline{P}$ can be out of range of $bNow$. Then the algorithm $Play$ is described as follows:

**step (S-1)**:initialize the counter
$Count = 0$
**step (S-2)**:input runner's step frequency
Input $P$ and $\overline{P}$.
**step (S-3)**:calculate the gap
If $|P - bNow| > E$ and $|\overline{P} - bNow| > E$

then Count++;
else if $|P - bNow| \leq E$ and $|\overline{P} - bNow| \leq E$
then Count−−;
**step (S-4)**:judge the close condition
If $Count > uBound$
then stop music and select another piece of music.
**step (S-5)**:repeat
Back to (S-2).

First, we assign a beginning value "0" to $Count$. When both $P$ and $\overline{P}$ are less than $bNow-E$ or more than $bNow+E$, we increment $Count$. When both $P$ and $\overline{P}$ are more than or equal to $bNow - E$ which is less than or equal to $bNow + E$, we decrement $Count$. Otherwise, $Count$ is not changed. If $Count$ exceeds the upper bound, the system stops the playing music, and executes another music selection using the current SPM (music selection module). Using both $P$ and $\overline{P}$, this module can detect changes of runner's step frequency exactly and avoid frequent changes of music. By default $E$ is 10 and $uBound$ is 20. The user can change these values. In the proposed system, a phase-synchronization[8] method is not implemented, and the next music just cuts in. This method will be implemented in future work.

## 4 EXPERIMENT

We carried out two experiments in order to confirm availability of the proposed system. In the first experiment, we determined how accurate the estimated SPM was and how long it took for music to change. In the second experiment, five subjects used and evaluated the proposed system. Music data used in the experiments was taken from the RWC Music Database: Popular Music [5, 6]. We used 100 pieces of music and BPM of each piece was calculated manually in advance. The experiment platform was Windows XP professional SP2 with an intel Pentium M 2.13GHz and 2GB memory.

### 4.1 Experiment to determine the accuracy of SPM estimation

In the first experiment, one subject ran on a running machine (Figure 5) changing his SPM. First, he ran at 80SPM and when music was played, he started to run at 120SPM. When the music changed, he started to run again at 80SPM. He repeated this until the music changed nine times. He also ran at 80 - 160SPM, 120 - 160SPM, and 120 - 200SPM. To determine the accuracy of SPM estimation, we defined precision ratio as Equation (3).

$$precision_k = \frac{\sum_{i=1}^{N} I_k(rSPM_i, eSPM_i)}{N} \quad (3)$$

where $k$ is the allowable range, $N$ is the number of music selection, $eSPM$ is the estimated SPM, $rSPM$ is the actual SPM, and $I_k(x, y)$ is the function which returns 1 if $|y - x| \leq k$, otherwise 0. We calculated both $precision_5$ and $precision_{10}$.

Table 1 shows the precision ratio of each set. Table 2 shows the average precision ratio at each SPM and how long it took for music to change. One can observe in Table 1 that $Precision_{10}$ is more than 80% in all cases, while $Precision_5$ is too low at 80 - 120SPM, which results from the low precision ratio of 80SPM as indicated in Table 2. This might be due to the difficulty in running just at 80SPM since 80SPM is too slow for most people to run at keeping their step frequency fixed.

Table 2 indicates that the proposed system can select the next music at every SPM within 20 seconds after runner's SPM changes. The lower SPM is, the longer it takes for music to change. The user can shorten the time by changing the value of $uBound$, however, too small $uBound$ may lead to frequent changes of music at higher SPM. In order that it may take the same amount of time for music to change at every SPM, we should make $uBound$ change automatically associated with SPM in future work.

| SPM | 80-120 | 80-160 | 120-160 | 120-200 |
|---|---|---|---|---|
| $Precision_{10}$(%) | 100.00 | 100.00 | 90.91 | 81.82 |
| $Precision_5$(%) | 50.00 | 90.00 | 81.82 | 81.82 |

**Table 1**. The precision ratio of music selection of each set

| SPM | 80 | 120 | 160 | 200 | Over all |
|---|---|---|---|---|---|
| $Precision_{10}$(%) | 100.00 | 87.50 | 90.00 | 83.33 | 90.21 |
| $Precision_5$(%) | 40.00 | 81.25 | 90.00 | 83.33 | 73.65 |
| Time for music change(sec) | 19.90 | 14.70 | 11.56 | 9.32 | 13.87 |

**Table 2**. The precision ratio at each SPM and the time for music change (average)

### 4.2 Experiment to investigate how the user feels

In the second experiment, we investigated whether the user felt pleased with the music selected by the proposed system. Five subjects (university students) ran on a running machine at different paces listening to the music selected by the proposed system and continued to run until music changed five times. They also ran at different paces listening to the music selected by a random selection system. In the random selection system, music was selected randomly. Music data used in the random selection system was the same as in the proposed system. In both cases, they answered how suitable each music had been for exercises ("suitability") and how pleasant the whole exercise had been ("pleasingness") on a scale of one to five (Table 3, Table 4). Table 5 illustrates a

| Evaluation | Criteria |
|---|---|
| 5 | very suitable |
| 4 | suitable |
| 3 | no opinion |
| 2 | unsuitable |
| 1 | not suitable at all |

**Table 3**. Evaluation criteria for “suitability”

| Evaluation | Criteria |
|---|---|
| 5 | very pleasing |
| 4 | pleasing |
| 3 | no opinion |
| 2 | boring |
| 1 | very boring |

**Table 4**. Evaluation criteria for ”pleasingness”

comparison with the random selection system. In both criteria, the proposed system achieved higher scores than the random selection system. The high score of “suitability” indicates that the proposed system can select music suitable for runner’s step frequency. The high score of “pleasingness” indicates that the proposed system can give pleasure to people listening to music while running.

| | Suitability | Pleasingness |
|---|---|---|
| The proposed system | 4.3 | 4.4 |
| Random | 2.7 | 2.6 |

**Table 5**. Evaluated ”Suitability” and ”Pleasingness” (average)

The distribution of the number of pieces of music judged suitable by the users in one experimental session is shown in Table 6. In Table 6, we can find that 86.0% of the music selected by the proposed system was evaluated as suitable for their exercises, while only 35.0% of the music selected by the random selection system was evaluated as suitable. These results suggest that the proposed system can select music suitable for user’s running exercises.

Table 7 shows the relation between BPM and “suitability” of the music selected by the proposed system. Table 7 implies that BPM is positively correlated with “suitability”. One subject remarked that he had felt comfortable while listening to the music selected by the proposed system especially when running at high SPM. It suggests that the proposed system is especially effective when the user is running at high SPM. This may be partly because at high SPM, phase-shifts are less obtrusive than at low SPM. More detailed research will be needed for a complete understanding of this reason.

**Figure 5**. A scene of the experiment

| Suitability | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Proposed System (%) | 0.0 | 0.0 | 13.0 | 43.0 | 43.0 |
| Random (%) | 20.0 | 33.0 | 13.0 | 28.0 | 7.0 |

**Table 6**. The distribution of the number of pieces of music judged suitable by the users

## 5 CONCLUSION

In this paper, we proposed an automatic music selection system for those who listen to music while running. We focused on runner’s step frequency and succeeded in developing a system that automatically selects music appropriate for running exercises by making a correlation between musical tempo and runner’s step frequency. Experimental results show that the system can estimate runner’s SPM accurately, and on the basis of the estimated SPM it can select music appropriate for users’ exercises with more than 85.0% accuracy, and makes running exercises more pleasing. To improve the proposed system, we need to use cross-fading technique to make transition between beats of both pieces of music seamless and have music phase-synchronized to increase user satisfaction. Future work will be dedicated to use other musical elements: musical genre, musical key, meter, timbre, melody, and harmony. And taking this step a bit further, we intend to correlate blood pressure, bodily temperature, or some other health information with various musical elements to make exercises not only amusing but also effective to improve human health.

## 6 REFERENCES

[1] Teemu Ahmaniemi. Influence of tempo and subjective rating of music in step frequency of running. *Proc. of*

| Suitability | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Averages of BPM | - | - | 115 | 119 | 153 |

**Table 7**. The relation between BPM and “suitability” of the music selected by the proposed system

*the 8th International Conference on Music Information Retrieval*, 2007.

[2] Apple computer. http://www.apple.com/.

[3] J.R. Brown. *The Effects of Stressed Tempo Music on Performance Times of Track Athletes*. Florida, 2005.

[4] Greg T. Elliott and Bill Tomlinson. Personalsoundtrack: context-aware playlists that adapt to user pace. *CHI’06 extended abstracts on Human factors in computing systems*, 2006.

[5] Masataka Goto, Hiroki Hashiguchi, Takiuchi Nishimura, and Ryuichi Oka. Rwc music database: Popular, classical, and jazz music databases. *Proceedings of the 3rd International Conference on Music Information Retrieval*, pages 287–288, 2002.

[6] Masataka Goto, Hiroki Hashiguchi, Takiuchi Nishimura, and Ryuichi Oka. Music genre database and musical instrument sound database. *Proceedings of the 4th International Conference on Music Information Retrieval*, pages 229–230, 2003.

[7] G. Husain, W. F. Thompson, and E. G. Schellenberg. Effects of musical tempo and mode on arousal on mood and spatial abilities. *Music Perception*, 20(2):151–171, 2002.

[8] Tristan Jehan, Michael Lew, and Cati Vaucelle. Cati dance: self-edited, self-synchronized music video. *SIGGRAPH Technical Sketch, Conference Abstracts and Applications*, 2003.

[9] Nuria Oliver and Fernando Flores-Mangas. Mptrain: a mobile, music and physiology-based personal trainer. *Proceedings of the 8th conference onHuman-computer interaction with mobile devices and services*, 2006.

[10] Nuria Oliver and Lucas Kreger-Stickles. Enhancing exercise performance through real-time physiological monitoring and music: A user study. *Proc. of Pervasive Health Conference and Workshops, 2006*, 2006.

[11] Nuria Oliver and Lucas Kreger-Stickles. Papa: Physicking and purpose-aware automatic playlist generation. *Proc. of the 7th International Conference on Music Information Retrieval*, 2006.

[12] Orio. A tutorial and review. *Foundations and Trends in Information Retrieval*, 1(1):1–90, 2006.

[13] Sony. http://www.walkman.sony.co.jp/.