Biosignal Controlled Recommendation in Entertainment Systems

Hao Liu

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Chapter 1

Introduction

With the increasing number of online entertainment stores and services, and the popularization of stationary and portable computing devices, we can more conveniently access entertainment content than ever. We can purchase music, games and movies from Amazon.com [112], listen to Internet radio services from Pandora [136] or Last.fm [104], watch videos on PPLIVE [145], and enjoy music or movies anywhere with portable multimedia players. All these services or devices provide massive entertainment resources. Not to mention the massive online content, even a small offline mp3 player with 30GB hard disk can hold more than 5 000 songs.

With such vast collections, a "long tail" distribution can be observed in user listening and watching history [30]. That is, in their collections, except for a few pieces that are frequently played, most are rarely visited. Even on desktop computers, it is often a tedious task to select favorite pieces from a large collection. Except the quantity of options, the quality of entertainment increases the difficulty for the user to find the right entertainment at the right location and time. Further, different entertainment contents may have different effects on the users [16, 74] and the users should choose the content that fits their physical conditions. Among these effects, faster music with a more upbeat tempo boosts respiration and heart rate [21]. Recent products such as Nintendo Wii fit [129] introduce physical fitness elements into entertainment. If the user does not have sufficient knowledge of these, even if the number of selections is small, it is still not easy for the user to find the preferred or best fit entertainment content. Therefore, recommendation systems become essential tools to help to bridge the gap between user requirements and available options.

Much effort has been devoted both in commercial and academic fields to develop entertainment recommendation systems in recent years. In the commercial field, Amazon.com recommends movies, Compact Discs (CD), and other products based on information of the users and their peers [112]; PPLIVE recommends movies watched by the user's peers [145]; Last.fm recommends personalized music by building a detailed profile of musical preferences and tastes based on the user's music listening history [104].

In the academic field, there are also many of these examples. By telling what movies the user likes and dislikes, MovieLens [123] makes personalized movie recommendations by generating a correlation coefficient between the user and every other user in the database. Movies were assigned a score based on their ratings by other users who have a high correlation coefficient. In addition to the preferences of the user and the peers, Ning-Han Liu et al. [128] use time for music recommendation. The recommendation system establishes the users' time aware behavior model by applying the decision tree learning on the listening history of users. After the model is established, the system is able to locate music which is suitable for the user at the current time by filtering the music information database. MusicSense [28] automatically suggests music when users read Web documents such as Weblogs. It matches music to a document's content, in terms of the emotions expressed by both the document and the music pieces.

However, despite all of these efforts, the current entertainment recommendation systems still require further improvements [5, 6]. For example, these recommendation systems did not explore how the entertainment can be used to improve user's comfort level intelligently and non-invasively; Biosignals were not incorporated into the recommendation process to facilitate the user to achieve a balanced bio state. This PhD project aims to contribute to these improvements by weaving biosignals non-intrusively into the entertainment recommendation process. It targets not only to help the user to find personalized content, but also to improve the user's (physical or mental) comfort level by the biosignal controlled content recommendations.

The rest of this chapter is organized as follows: section 1.1 elaborates the motivation and the goal of the biosignal controlled recommendation in entertainment systems. The SEAT project in which this PhD project was carried out is introduced in section 1.2. In section 1.3, the reasons of choosing a heart rate controlled in-flight music recommendation system as the application domain are explained. The motivation and the goal of it are also elaborated. The research questions are formulated in section 1.4. Section 1.5 introduces the main content of this thesis.

1.1 Biosignal controlled recommendation in entertainment systems

The current entertainment recommendation methods can be categorized into four categories: Content Based Filtering (CBF), Collaborative Filtering (CF), context-based filtering and hybrid recommendation [5]. Among them, CBF and CF are traditional recommendation methods in entertainment systems. Context-based filtering methods only emerged in the recommendation paradigm in recent years.

CBF methods recommend the content based upon the description of the content items and the profile of the user's interests. The CF mechanism uses the correlation between the users based on their ratings or their profiles to find the other users with similar interests. Users with common interests recommend to each other. Context-based filtering methods recommend the content based on the context information (location, time, etc.). Hybrid recommendation combines CBF, CF and context-based filtering approaches to construct recommendation tactics.

Each of these recommendation methods has successful applications. CBF has Pandora [136] and MusicSurfer [29]. CF has Last.fm [104] and Ringo [174]. Context-based filtering method is used by Lifetrak [151] and PersonalSoundtrack [47] to incorporate sensors to bring the activity information into the recommendation process. As an example of hybrid approach, Yoshii et al. [214] combine both CBF and CF to construct a music recommendation system.

However, despite the properties of the content, the preferences of the users, and the context, hardly any of these methods take into account the physiological and psychological states of the user. Only few researches incorporated biosignal into the entertainment recommendation process. Although there are lots of studies that investigate the biosignal effects of the entertainment on the user [44, 124, 179, 216], only a few studies explore how to use these results to recommend personalized entertainment to improve the user's experiences, one of which is for example the level of comfort. The state of the art of related works will be reviewed and discussed in detail later in chapter two.

Based on this observation, this PhD project dedicates to develop a new entertainment recommendation system that incorporates biosignal into the recommendation process. The biosignal is used as an indicator of the user's physical or mental conditions (stress, heart rate, etc.). The relation between the entertainment content and user's biosignal is utilized to recommend biosignal controlled personalized content to improve the user's (physical or mental) comfort level (figure 1.1).

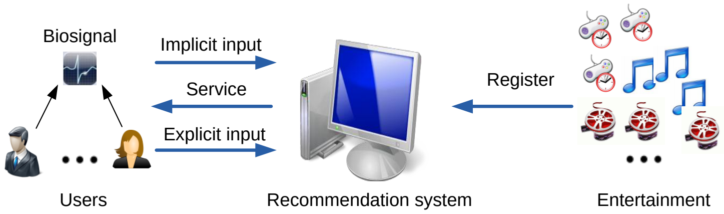


Figure 1.1: Biosignal controlled recommendation system

Biosignal is a term for signals that can be continually measured and monitored from a person [207]. Among the well-known biosignals are ECG (Electrocardiogram) and GSR (Galvanic skin response). ECG is a transthoracic interpretation of the electrical activity of the heart over time captured and externally recorded by skin electrodes [10]. By tracing ECG, information such as heart rate and heart rate variability can be determined (measured or calculated) [154]. GSR is a method of measuring the electrical resistance of the skin [208]. In many researches it is used as an indicator of stress [139].

Comfort is a complex concept, consisting of both objective ergonomics requirements and subjective impressions [46]. The exact definition of comfort is beyond this thesis. In this thesis, the level of comfort is counter-measured against the level of stress.

Entertainment plays an important role in stress reduction. In literature many researchers used music for stress reduction. David [41] conducted an experiment and showed that "relaxing" music can be used to decrease stress and increase relaxation in a hospital waiting room. Literature also shows that in order to reduce physical discomfort, contraction of muscles is very important [196, 197]. Muscle activity helps to keep the blood flowing through the veins. If the user wants to play Wii games [129], he/she must move with certain exercise patterns which are in accordance with muscle activities. If the user plays properly, the physical stress can be reduced.

Stress can be provoked by many events that occur in our lives: moving, changing jobs, and experiencing losses [32, 69]. We may also face many daily hassles that occur routinely or accidentally: being stuck in traffic, deadlines, and conflicts with the boss or colleagues. Excessive stress may cause us to become aggressive, over-reactive and even endanger our health [177].

One of the methods to reduce stress is to be relaxed with or distracted by interesting entertainment activities. However, if there is not a recommendation system and available entertainment options are too many, the user tends to get disoriented and will not be able to find the most appealing service. Difficulties in this process would introduce more stress. Moreover, even if the number of available options is small and the user manages to find it, it is still not guaranteed the found activity or content is suitable for reducing the user's (physical or mental) stress. In either case, a proper recommendation system would be helpful, which is exactly the focus of this PhD project.

1.2 SEAT

This PhD project was carried out in the context of European project SEAT (Smart tEchnologies for stress free Air Travel) [169]. SEAT was funded by the European Commission DG H.3 Research, Aeronautics Unit under the 6th Framework Programme, under contract Number: AST5-CT-2006-030958. The SEAT project commenced in September 2006 and finished in November 2009. The project consortium contains 12 partners: Czech Technical University (CTU), Eidgenoessische Technische Hochschule Zuerich (ETHZ), Imperial College London (IC), Queen Mary and Westfield College (QM), Technische Universiteit Eindhoven (TUE), Acstica y Telecomunicaciones, S.L (ACU), Antecuir S.L. (AN), Asociacin de Investigacin de la Industria Textil (AIT), Design Hosting Software Ltd. (DHS), Instituto Technologico del Calzado y Conexas (INE), StarLab (ST), and Thales (TH).

The SEAT project focuses on an integrated system that creates a healthier and more comfortable cabin environment and provides a high level of customer focused services. There are four main research directions in the SEAT project

Figure 1.2: Overview over the four main objectives of the SEAT project

(figure 1.2): (1) Flight entertainment: to develop on-board adaptive entertainment systems to increase the passenger's comfort level. (2) Vibration and noise control: to develop systems to suppress noise overall, as well as for each passenger and develop a novel approach for active/passive vibration reduction. (3) Condition monitoring system: to develop technologies that enable personalized healthier cabin environment (temperature, pressure, air-flow and humidity). (4) Smart seat: to develop smart sensor technologies that embeds in textiles for non-intrusive passenger and environment sensing. TUE leads the in-flight entertainment research direction.

1.3 Heart rate controlled in-flight music recommendation system

In the SEAT project, heart rate controlled in-flight music recommendation system is chosen as the research carrier of the biosignal controlled recommendation in entertainment system. The reasons are as follows.

Firstly, heart rate, the number of heart beats per minute (BPM), is chosen as an instance of the biosignal. It can be computed precisely from the ECG signal. BPM tells whether the user's heart rate is normal or not. If not, it may relate to stress [102] [191]. Moreover, the heart rate variability indicates mental stress change (increase, reduction) [37]. Another reason we choose heart rate instead of GSR is that the heart rate measurement method can be done non-intrusively using for example Emfit L-Series sensor [51]. A non-intrusive measurement of any biosignal is vital in long haul flight environment. During the SEAT project, the consortium did not find non-intrusive measurement methods for GSR.

Secondly, music is chosen as the instance of entertainment. The reasons are: (1) music is ubiquitous in our daily life, according to a recent report, the prevalence of most leisure activities, such as watching TV or movies or reading books, has been overtaken by music listening [141]; (2) finding preferred music tracks from a large space is hard for a user; (3) music is created by artists to express emotions and in some cases, to induce relaxation, which fits well the focus of the project.

Thirdly, literature shows that there are relations between the music and the user's heart rate and stress [111]. Sleight [21] finds that listening to music with a slow or meditative tempo has a relaxing effect on people, slowing breathing and heart rate. Listening to faster music with a more upbeat tempo has the opposite effect – speeding up respiration and heart rate. Miluk-Kolasa et al. [124] showed that music was one of the relaxing adjuncts in modulating the ascent of autonomic responses to negative stress. David [41] conducted an experiment and showed that "relaxing" music can be used to decrease stress and increase relaxation in a hospital waiting room.

Fourthly, travel by air, especially over a long distance, is an unusual activity for human being. The unusual economical cabin environment (lower air circulation, limited space, lower humidity, etc.) of the long haul flights causes discomfort and stress for a large group of passengers [206].

Currently, in-flight music service, which is part of the in-flight entertainment (IFE) system, is commonly installed on long haul flights as one of the pastimes for the passengers. However, the current in-flight music systems do not explore how the music can be used to increase the passenger's comfort level. The music is simply broadcasted through a limited number of channels, or delivered interactively as audio on demand. This provides mental distraction, however it is unclear whether it leads to reduction or increase of the passenger's comfort level. Further, most of these in-flight music systems are built based on a preset concept. They assume a homogeneous passenger group that has similar tastes and desires. They present the same user music interface and contents to every passenger. To get preferred music service, the user needs to explicitly interact with systems to get desired music services from the provided options. To allow the passengers to have some choices to some degree, a large collection of music is often offered. If the available choices are many and the interaction design is poor, the passenger tends to get disoriented and not to be able to find preferred music [116].

To improve the situation, this PhD project dedicates to develop a heart rate controlled in-flight music recommendation system. It aims to incorporate the passenger's heart rate signal (as an indicator of discomfort or stress) measured non-intrusively feeding into a music recommendation process. The music features, passenger's music preference and heart rate are taken into account to recommend music playlists to the passenger. By letting the passengers to listen to the recommended music playlists, the system aims to keep passengers' heart rate within a normal range and improve their comfort level during long haul air travels.

1.4 Research questions

This PhD project aims to contribute to the development of the next generation of entertainment recommendation systems in two aspects: (1) mechanisms to incorporate the biosignal non-intrusively into the recommendation process; (2) biosignal controlled entertainment recommendation strategies to improve the user's physical and/or mental comfort level. Heart rate controlled in-flight music recommendation system under the SEAT project is chosen as the carrier for the experiments and the research.

The hypothesis is that the passenger's heart rate deviates from the normal due to the unusual long haul flight cabin environment. By properly designing a music recommendation system to recommend heart rate controlled personalized music playlists to the passenger, the passengers' heart rate can be uplifted, down-lifted back to normal or kept within normal, so that their stress can be reduced. Research questions are formulated based on these hypotheses:

(1) Does the passenger's heart rate deviate from the normal during long haul air travels?

(2) Can the long haul passenger's heart rate be uplifted or down-lifted if it deviates from normal and can it be kept within a normal range by a properly designed music recommendation system?

(3) Can the passenger's stress be reduced by a properly designed music recommendation system?

(4) To answer these questions above, a system has to be designed and implemented for experiments and possibly as a reference for the implementation in real flights. What kind of system framework or architecture is needed for such a system?

1.5 Content of this thesis

The rest of this thesis is organized as follows. Related works is reviewed in chapter 2. The current installed and commercially available in-flight music systems, the current music recommendation mechanisms are investigated. Thereafter, the enabling technologies which include context-aware systems, user profiling, the cybernetic control system, the relation between the heart rate and music, and the stress model which enables designing the heart rate controlled in-flight music system are explored.

In chapter 3, the objective of the heart rate controlled in-flight music recommendation system is analyzed and summarized: if the user's heartbeat rhythm is disrupted and the heart rate is higher or lower than the normal heart rate, the system recommends a personalized music playlist to the user to transfer her/his heart rate back to normal. If the user's heart rate is normal, the system recommends a personalized music playlist to keep the heart rate within the normal range. An adaptive framework which integrates the concepts of context adaptive systems, user profiling, and methods of using music to adjust the heart rate into a feedback control system is designed to achieve the objective.

In chapter 4, a software platform independent architecture to support the framework is designed with five abstraction levels from the functionality point of view. Thereafter, the details of the implementation of the architecture are introduced. In chapter 5, the design concepts are validated according to the functional requirements. User experiments were conducted to validate the hypothesis and the system design. Long haul flights from Amsterdam to Shanghai were simulated for the experiments. Chapter 6 concludes the thesis. The limitations of this thesis are also discussed. Future work is discussed as well.

Chapter 2

Related Work

In this chapter, firstly, currently installed and commercially available in-flight music systems are reviewed. Secondly, current music recommendation methods developed in both academia and industry are investigated. Finally, related work which enables the heart rate controlled in-flight music recommendation system design is explored.

2.1 Current in-flight music systems

Music service is an important part of the IFE system ever since IFE becomes available to aircraft passengers. According to the Guinness world records 2009 [65], the first in-flight movie was shown in 1925 on a flight from London to Paris (figure 2.1). After World War II, commercial flights became available for daily public transportation. Entertainment was then requested by passengers to help pass the time. It was delivered in the form of projector movie during lengthy flights, in addition to food and drink services (figure 2.2). In-flight entertainment systems were upgraded to CRT (Cathode Ray Tube) based systems in the late 1980s and early 1990s. In 1985, using Philips Type Cassette technology, the first audio player system was offered to the passengers by Avicom [13]. Around the same time, CRT-based displays began to be installed on the ceiling of the aisles of the aircrafts. In the mid 1990s, the first in-seat video systems began to appear, and LCD (Liquid Crystal Display) technology started to replace CRT technology as the display technology for overhead video. In the late 1990s and early 2000s, the first in-seat audio/video on-demand systems began to appear [201].

In the following subsections, after the current installed in-flight music systems are investigated, the latest commercially available in-flight music systems are also explored.

Figure 2.1: In-flight movie in 1920s (this photo is taken from [65])

Figure 2.2: 1950s: A projector being fitted into a plane for showing in-flight movies (this photo is taken from [64])

2.1.1 Current installed in-flight music systems

To allow each airline the freedom to configure the aircrafts according to its budget and marketing strategies, airplane producers (e.g., Boeing and Airbus) provide customized IFE solutions. In 2006, we investigated the installed IFE systems in the aircrafts of Airlines of Lufthansa, Air France, British Airways, American Airlines, Delta Airlines, and Japan Airlines [114]. These airlines are top airlines in Europe, North America and Asia from total scheduled passengers point of view. Scheduled passengers are those who travelled with scheduled flights.

All the in-flight music systems installed in investigated airlines' aircrafts are implemented based on the preset concept about what customer likes and assumes as a homogeneous passenger group that has similar tastes and desires. They present the same interface and music content to each passenger no matter whether those passengers come from highly heterogeneous pools or have different music preferences (figure 2.3).

Figure 2.3: American Airlines' 767-300 IFE system in business class (this photo is taken from [1])

To get desired music services during air travel for recreation, the user needs to interact with the IFE system. By means of a touch screen or an in-seat controller (figure 2.4), the user browses though extensive lists and selects the desired music tracks from provided options. Too many options or too much of work to orient themselves in these options may cause users to get lost [116,200]. When this is the case, the system and the controllers do not contribute to improving the situation, but make the situation only worse.

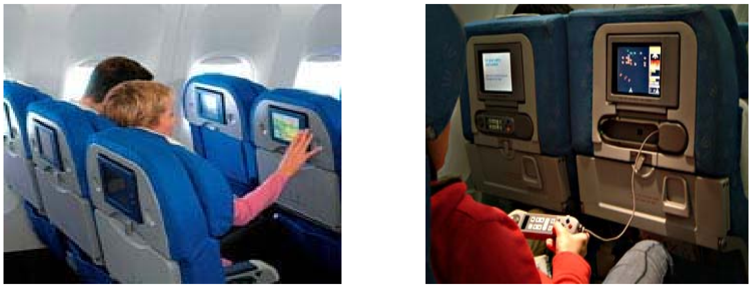


Figure 2.4: Interactions between the passenger and the in-flight music system (this photo is taken from [8])

2.1.2 Commercially available in-flight music systems

Currently, the IFE system market is dominated by Panasonic [135], Rockwell Collins [155] and Thales [194]. In 2006, we investigated the latest commercially available IFE systems from these companies [114].

Panasonic X-series is the first IFE system based on the research of passengers' preferences and consumer trends. These research results were used to provide customized IFE systems to airlines. The X-series delivers high-speed communication tools and state of art entertainment, including audio/video on demand, in-flight email, internet access and other options for passengers. Passengers are in complete control to select from the provided options. As to music, passengers can create, sort, and store personal audio playlists.

Rockwell Collins provides several IFE systems with their TES series. Among them eTES has not only all the benefits of other TES - such as audio/Video on demand and interactivity but also with the same high-speed network connectivity as in I-5000 from Thales. The system provides dynamically built menu pages. Menu choices are generated based on each request, creating a personalized menu for each passenger. All eTES pages are created in the language selected by the passenger. Localized music title, language choice, start, stop, rewind and pause controls are all available. Further, eTES collects usage data and provides the data analysis to assist airlines in determining an optimal content mix, thereby minimizing content costs while maximizing passenger satisfaction.

TopSeries is an in-flight entertainment product from Thales. The latest system is I-5000 where all digital video and audio are provided on-demand with greater bandwidth using a gigabit Ethernet network. With a modular design, the system is able to support overhead displays, in-seat distributed terminals and on-demand content distribution simultaneously on a single aircraft.

In summary, the latest commercially available IFE systems did make progress in improving the performance of hardware and software platform, providing an increasing number of entertainment options with improved interactivity. However, the problems found previously in installed in-flight music systems still exist [114].

2.1.3 Summary

The adaptive relations among IFE producer, airline, passenger and IFE system are summarized as follows. Airlines buy customized IFE systems from IFE producers according to the budget and the market demand. During the flight, to listen to music for recreation, the passenger can browse and select desired pieces of music from the provided options step by step via the interactive controller or touch screen. The airline may record the passenger's interaction and behaviour via a logging system during this process, or may collect the passenger's feedback using questionnaires afterwards. Based on the collected data and feedback, the airline can further improve the music system interface and the music content collection to provide passengers with better music services. The airline may also ask the IFE producer to optimize the IFE system. However, in the current implementations, no passenger's implicit inputs (e.g. profile, preferences, etc.) are used to facilitate music browsing, selection and recommendation. Although airlines have realized the importance of installing IFE systems to improve their passengers comfort level, possibilities in utilizing both the user's implicit and explicit input, improving the adaptability of the offered content, thus further reducing the stress are yet to be explored (Figure 2.5).

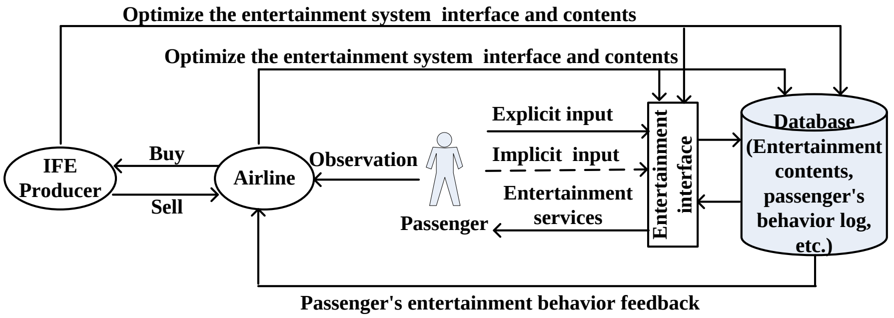


Figure 2.5: Adaptive relation between IFE producer, airline, passenger and IFE system

2.2 Current music recommendation methods

A music recommender system aims to support users in selecting music items while interacting with a large collection of music pieces. Since the middle of the nineties, there has been much work done both in academia and industry on developing music recommendation systems. They are usually classified into the following categories based on the recommendation methods they used: content-based filtering, collaborative filtering, and hybrid approaches. These methods are based on the information from users, peers and the music items. In recent years, along with the development of information and communication technology, context based filtering emerges as an important recommendation paradigm to provide context-aware music services. In this method, context information (location, time, etc.) is considered for music recommendations. Next, these recommendation methods are introduced and discussed in more details.

2.2.1 Content-based filtering

Content-based filtering recommends music to a user based on the description of the music and the user's music preference. Although the application areas differ, content-based music recommendation systems share in common descriptions of music items, user's music preferences, and algorithms to match music items to the user's preferences [18, 138].

Much work has been done in both commercial and academic worlds to develop content-based music recommendation systems [11, 29, 31, 68, 80, 103, 136, 171]. In the commercial field, Pandora [136], one of the largest online radio providers, recommends music according to the songs, the albums or the artists that the user has been listening to. The music recommendation is based on the similarity. The similarity measure is based on 150 "features" of the music described by a team of professional music analysts.

In the academic field, the music recommendation method proposed by Zehra Cataltepe and Berna Altinel [11] is based on the listening history and music clustering. According to different sets of audio features of all available songs, different clusterings are obtained. Users are given recommendations from one of these clusterings. A different approach, based on user modeling, is found in MusicCat, an agent-based recommendation system [31]. In MusicCat, the user model contains information about the user's habits, preferences and user defined features. MusicCat can automatically choose music from the user's music collection according to the user model. A more raw data based approach is used in MusicSurfer [29]. MusicSurfer automatically extracts information related to instrumentation, rhythm and harmony from the audio signal. Together with efficient similarity metrics, the extracted information allows navigation and filtering in multimillion music items without the need for the metadata or human ratings.

The advantages of content-based filtering are: (1) it is capable of classifying and recommending music items based on the similarity of the content features; (2) it is suitable for users who have special explicit preferences and those who know exactly what they want; (3) no need of information from other users, which means no connectivity is needed among the users and the recommendation can be done standalone with only the user and his/her music collection. The disadvantage of the content-based filtering is that it is limited by the predefined features that are explicitly associated with the items to be recommended [5].

2.2.2 Collaborative filtering

The collaborative filtering mechanism uses the correlation between users with similar tastes and preferences in the past. Users with common interests recommend music tracks to each other [18, 163, 185]. The principle works as follows: if the songs or artists a user likes occur commonly in other users' playlists, the user will probably also like other songs or artists that occur in those playlists. According to [40], "if your collection and somebody else's are 80% alike, it's a safe bet you would like the other 20%".

Collaborative filtering has been widely used and developed in the commercial and academic worlds. In the commercial field, one of the most popular on-line music recommendation engines that use collaborative filtering is Last.fm [104]. It boasts that it has 15 million active users and that 350 million songs are played every month. Last.fm builds a detailed profile for each user according to the musical taste by recording details of the songs the user listens to. This information is transferred to Last.fm's database via a plug-in installed into the user's music player. The site offers numerous social networking features in order to collect information from the other uses in one's network. It can recommend and play artists similar to the user's favourites. In the academic field, Ringo is a pioneering music recommendation system based on the collaborative filtering approach [174]. In Ringo, the preference of a user is acquired by the user's rating of music. Similar users are identified by comparing their preferences. Ringo predicts the preference of new music for a user by computing a weighted average of all ratings given by the peer group of similar preference.

The advantages of the collaborative filtering mechanism are: (1) it is capable of filtering information where the content is hard to be analyzed, such as extracting the rhythm of the music; (2) it can avoid inaccurate content analysis by relying on other users' experiences; (3) it is capable of recommending new items that are not yet known by the user and that are not in the user's collection. There are several disadvantages with this approach. First, it depends often on human ratings. Second, its performance decreases when data gets sparse, which happens often with web related items [5, 165].

2.2.3 Context-based filtering

Traditional content-based filtering and collaborative filtering methods make their recommendations in the two-dimensional space (user and music information). They do not consider additional context information that may be crucial in some applications. However, we know that users' music preferences are influenced by context information, such as the time, location, emotion, or activity, but this type of information is not exploited by content-based and collaborative filtering music recommendation methods. Context-based filtering aims at improving user satisfaction level by tailoring music recommendation according to the context information.

In recent years, there has been some work done towards context-based filtering recommendation [34, 47, 78, 128, 151, 153, 170]. Lifetrak [151] is a system that uses context information for music selection. The music items are represented by tags which are described by the user. The tags link the music items to context in which they should be played. Context information includes location, time, velocity, weather, and traffic which are measured by Global Positioning

System (GPS), accelerometers, timer, etc. sensors. User feedbacks are utilized to rate a music item more or less likely to be played in a given context. Lee [105] incorporates season, month, day of a week, weather, and temperature context information into the music recommendation process. Based on these information, the music recommender infers whether a user wants to listen to music and whether the genre of the music suitable to a user's context. Liu [128] adds time scheduling to the music playlist, and combines classification technology of decision tree to suggest users the suit music.

PersonalSoundtrack [47] and DJogger [24] sense users' activity level and use this information to select music. PersonalSoundtrack matches music beats per minutes (BPM) to the user's steps per minute. The user's step is measured by an accelerometer. Likewise, DJogger links user pace to music BPM. The difference with PersonalSoundtrack is that the music BPM changes based on the pace of the user's workout goals.

In [170], Jarno Seppnen and Jyri Huopaniemi propose compelling scenarios for future mobile music. In scenarios, location, time, mood, and activity context information are considered to provide users context-aware mobile music services.

Context-based filtering is a hot research topic since it bridges the gap between recommender systems and other areas of research such as context-adaptive systems, ubiquitous computing, and wearable computing. There is a lot to be done to improve user satisfaction level through context-based filtering recommendation. Improvement directions include incorporating more broad and precise context information (mood, emotion,etc) into the recommendation process, embedding the recommendation unobtrusively into users' daily life.

2.2.4 Hybrid recommendation

In most of the literature, the hybrid approach is a combination of content-based filtering and collaborative filtering [27,60,106,113,173]. To overcome the disadvantages of them, several researchers proposed a combined method to construct a recommendation mechanism. Yoshii et al. consider user ratings (collaborative filtering) and content similarity (content-based filtering) to recommend music [214], whereas Chen et al bases their approach on music grouping (collaborative filtering) and user interests (content-based filtering) [33].

In recent years, the hybrid recommendation is extended with context-based filtering recommendation. For instance, uMender takes context information, musical content and user ratings into account to offer personalized and context-aware music recommendations [184].

2.2.5 Summary of the methods

In this section, current music recommendation methods are categorized into content-based filtering, collaborative filtering, context-based filtering and hybrid recommendation. In each category, the method is explained and its applications are investigated.

Traditional music recommendation methods include content-based filtering and collaborative filtering. These approaches operate in two dimensional spaces of the user and the music.

Content based filtering is capable of clustering similar music tracks based on content features. After the user selects an item, similar music items can be recommended to him/her immediately. Unfortunately, its recommendation is limited by the content features that can be extracted.

Collaborative filtering considers the correlation between users. Similar users recommend music items to each other. It is capable of recommending music without accurate music content analysis. However, at the system initialization stage, it will face the cold-start problem, that is, the system cannot effectively serve its duty yet until it has gathered sufficient information about the users and items.

In recent years, context-based filtering is emerging as an important recommendation method. Location, time, activity, etc. information are utilized to provide user context-aware music services.

Content-based filtering, collaborative filtering and context-based filtering recommendation methods have their own advantages. However they cannot perform well in every situation. In some applications, they are combined (hybrid recommendation) to improve the recommendation performance.

2.3 Enabling technologies

This section reviews the technologies that can be used to enable heart rate controlled in-flight music recommendation systems to increase passengers' comfort level. Firstly, context-adaptive systems which enable incorporating biosignals into the music adaptation process are explored. Secondly, User profiling technology is described. User profiling has been suggested to enable personalization and to decrease unnecessary dialogues between the user and the system. Thirdly, related work is investigated with regard to the relation between the heart rate and music. Fourthly, the theory of cybernetics control systems is introduced. Cybernetics control systems use information, models, and control actions to steer towards and maintain their goals, while counteracting various disturbances. This theory is used later in the design to keep the passenger's heart rate at normal. Finally, the current measurements of the stress are investigated, which is important for evaluating whether passengers comfort level is improved by the system or not.

2.3.1 Context adaptive systems

In section 2.1.1, we have seen that, to enjoy the desired music services, the user must manually browse the menu before being able to find them. From the adaptive system point of view, the current in-flight music systems are at most user-adaptive systems where the characteristics of the users and the tasks are considered for adaptations.

Classical user-adaptive systems are understood as intelligent systems adapting to user needs [38]. In the eighties, the focus of user-adaptive systems was a user model defined by personal characteristics and preferences together with a task model defined by task characteristics [38, 202].

User-adaptive systems adapt to the individual user based on the analysis of the interaction between users and the system [58, 150, 204]. User-adaptive systems adapt four characteristics of the system behavior to the user [131]: (1) information and service; (2) functionality; (3) information presentation; and (4) human-computer interaction.

In the nineties, the adaptive system computing paradigm moves from the user adaptive system to the context-adaptive system. Except for the characteristics of the users and tasks, context adaptive systems also consider contextual information for adaptation [120, 126, 187]. Context is any information that can be used to characterize the situation of an entity. An entity can be a person, a place, or an object that is considered relevant to the interaction between a user and an application, including the user and the application themselves [3]. It is a powerful and longstanding concept in human-computer interaction. Interaction with the computer is either explicit (e.g., pointing to a menu item), or implicit (context). Implicit interaction (context) can be used to enrich or interpret explicit acts, making explicit interaction more efficient. Thus, by carefully embedding context information into adaptive systems, the user can be served with desired results with minimal effort.

According to [183], four dimensions are often considered for the context: (1) the location of the user in either the information space or in the physical space, (2) the identity of the user implying the user's interests, preferences and knowledge, (3) the time (time of working hours, weekend, etc.) and (4) the environment of the current activity [166]. These dimensions are currently exploited for context-aware, ambient and pervasive computing [77]. The most prominent dimension is the location because the availability of small and portable devices and location awareness technologies allow variant uses at different places. Information and communication systems more and more support mobile activities during the whole process distributed over time [72, 76], location [55, 71, 75, 76] and social communities [211].

Next, based upon the description of three functions of adaptivity: (1) interaction logging [148], (2) adaptation inference [168] and (3) adaptation performance [17], we describe context-adaptive systems and the role sharing between the system and the user during the adaptation process. At the end, the state of the art examples are presented for understanding context-adaptive systems in different fields of information and communication services.

Process steps of context-adaptiveness

Three sequential steps are distinguished during the context-adaptive process in [131]. (1) The interaction logging function. This step first receives the incoming interaction events. Then, it categorizes the events according to predefined dimensions of usage process characteristics. Finally, the result is reported to a central adaptation inference function. (2) The adaptation inference function. This step first analyses the incoming interaction event messages. Then, it evaluates them according to predefined rules and algorithms. Finally, adaptation activities to be performed are generated. (3) The adaptation performance function. This step consists of adaptations modifying or complementing the system's content and service selection, the systems functionality, the system's presentation methods and the system's interaction techniques.

The interaction logging function indicates the observation of the user who performs a task with the system registering all relevant information and records this data in a systematic and continuous way. The adaptation inference function refers to the intelligent analysis of the accumulated data through statistical methods and learning algorithms. Hereby, different models about the user, task, environment, domain, and system represent the knowledge needed for drawing inferences. The adaptation performance function transfers the results of the inferences into respective options of operations adapting the functions or the interface of the system to the user's current needs. This understanding of the adaptation process can be applied to structure the functions of a context-adaptive system.

As indicated by [131], compared to a user-adaptive system, the complexity of a context-adaptive system increases. The reason is because context-adaptive systems need to observe and adapt to more variables. These variables include the location, time, environment, domain, physical conditions and social actors. Especially, sensors are needed to acquire the location, the physical and social environment and the technical infrastructure information to establish a current context profile.

Application of context-adaptive systems

There are several areas of application for context-adaptive systems. According to [131], three areas of them are of prominent importance: (1) mobile shopping assistants, (2) mobile tour guides, and (3) mobile learning assistance.

Mobile shopping assistants help users to find specific locations for products or services for currents needs [25, 83, 107, 152, 210]. An example is the cheapest gasoline stations in the vicinity of the user [83].

Mobile guides are the second important area of applications for context-adaptive systems. They can help users to find a specific destination or to find items of interest along a path in the physical space [2, 35]. The central task for mobile guides is to map the interest profile of the user with the attribute profile of the environment. City guides [2] and museum guides [14,63,142,178] are the main domains for mobile tour assistants. Fraunhofer IIS has developed several context-adaptive guiding systems: HIPS [132], CRUMPET [167], LISTEN [193] and SAiMotion [130]. In all these systems the current location of a user and corresponding domain objects in the environment were continuously identified and mapped to the interests and tasks of the user.

Mobile learning assistance is a third important area for context-adaptive systems [20, 43, 91, 108]. Mobile learning reflects the current location to specify

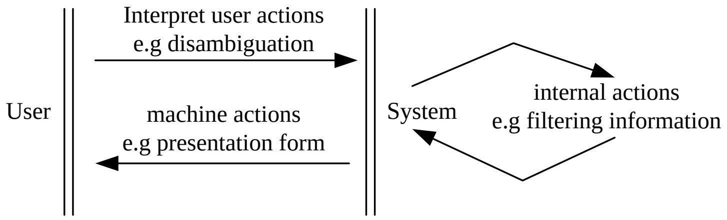


Figure 2.6: Three main functionalities of the user profile in adaptation (adapted from [88])

the learning demand of a user to perform his or her task. Mobile learning has close relations to mobile guide; both have to instruct users. For mobile guides, the goal is more interest driven by the personality of the user and more curiosity or fun oriented. For mobile learning assistance, the goal is more task-driven by the job of the user and more performance oriented.

2.3.2 User profiling

The information of a user that reflects his/her Needs Requirements and Desires (NRDs) on the preferred system behaviors explicitly or implicitly is called a user profile [162]. It is usually to be integrated into the system to import the user knowledge to the system, which enables automatic personalized system behavior adaptations and avoid "unnecessary" dialogues between the system and the user. Next we investigate existing practices of user profiling. The role of a user profile in an adaptive system is firstly investigated. The formation of a user profile is then discussed. Following that, user profile modeling approaches and the possible sources of user profiles are investigated.

Role of a user profile

Judy Kay [88] identified three main ways that a user profile can assist in adaptation by (figure 2.6):

(1) Interpreting user actions to eliminate the ambiguity;

(2) Driving the internal actions of the system. This is the goal of systems which filter information, select the right system functionalities, etc. on behalf of the user;

(3) Controlling machine actions to improve the quality of the interactions.

The role of the user profile to interpret user actions to eliminate the ambiguity has been explored by Shari Trewin and Pain [195]. Their system monitors the typing problems displayed by users with motor difficulties so that it could identify difficulties such as errors caused by pressing a key for too long.

The internal actions of the system include helping the user to find or access relevant information, tailoring information presentation to the user, or adapting the interface to the user [87]. Goel [62] implemented an adaptive system that uses the user profile to create a view of a subset of a web site most relevant to the user. Storey [181] uses the user profile to increase the accuracy of web pages returned from the Web.

The machine actions to be controlled by a user profile improve the quality of the interaction. A simple example of this involves the system tailoring its presentation form for the user. More sophisticated cases involve adaptation of the content in addition to the form of the presentation. Zhao [217] discussed the design considerations of a personalized browser for inexperienced users. The advantage of the browser is that it can be tailored to personal needs and preferences. User interface adaptation and personal information space adaptation are combined to address simplicity and usability issues.

Formation of a user profile

Both user adaptable systems and context adaptive systems need the user profile to map the user's NRDs on desired system behaviors. It is used to enable personalized and context-aware adaptations and reduce the redundant explicit inputs from the user.

For user-adaptive systems, the formation of the user profile is a subset of the intersection between the user model and the available system behaviors. The user model includes the user's personal demographic information (age, gender, grade...), user's capabilities (background knowledge, proficiency, cognitive and non-cognitive abilities...), and the user's interests. The system behaviors include functionalities, contents, presentation forms, and the ways to deliver the service. The intersection between the user model and the available system behaviors includes the items in the user profile which represent the user's NRDs on the preferred system behaviors.

Generally, the more of these items are included in the user profile, the more personalized behaviors the system could bring to users. However, at the same time, the more complex the user profile, the more work the system needs to create, manage and update it. So, a system designer needs to balance. Kavcic [87] points out that a perfect user model for adaptation in educational hypermedia should include all features of users that affect their learning, performance, and efficiency. However, because the construction of such a complex model is difficult, simplified models which are subsets of the intersection between the complete user model and the educational hypermedia system behaviors are used in practice. Similar examples and conclusion can also be found in [95].

For context-adaptive systems, the main content of the user profile is a subset of the intersection among not only the user model and the available system behaviors, but also the context. The information items in this subset reflect the user's NRDs on the preferred system behaviors in a particular context.

The user profile in [215] is composed of two parts: user's preferences and history activities. The user can update the preferences according to his/her specific context. The history is ordered by time-space as well as the theme of the activities. A similar example is also found in [186], the user profile is categorized into two parts according to their characteristics: one is static, the other is dynamic. The items in the profile are considered static if a user can initially input these items, e.g., his service-specific desires, through a Graphical User Interface (GUI). The static part includes personal information such as name, age, and address. The dynamic part includes the user's preference items which depend on the context.

User profile modeling approaches

Generic user profile models [180] have been considered for user profile modelling. These models have two major goals: 1) generality: which allows the model to be usable in a variety of application domains; 2) expressiveness: where the model is able to express a wide variety of assumptions about the user. However, due to the vast increase of possible scenarios with their inherent demands and constraints, it is unlikely to have a generic user model to work for a variety of application domains [94]. Instead, as Kobsa [94] pointed out that one can expect to find a variety of generic user modelling systems, each of which is going to support only a few of the very different future manifestations of personalization. According to Kobsa, currently, the research on a generic user profile model is still mostly in theory, not yet in practice.

Most user profiles are application specific [118]. As we just mentioned, even in these specific applications, the information items in the profiles include a static part and a dynamic part [186]. The modelling approaches of these two parts are different.

For the static part, information items such as the gender or the expertise level can be simply modelled with Attribute-Value Pairs [36]. Attributes are terms, concepts, variables, facts that are significant to the system and the user, and values can be for example a Boolean, a real number, or a text string. More complex items such as the user's knowledge which consider uncertainty are modelled with more complex modelling approaches such as rules with certainty factors, fuzzy logic, Bayes probability networks or Dempster-Shafer theory of evidence [87]. If there are relations within the static information elements, the hierarchical tree modelling approach [19, 61, 62, 110, 175] can be used. The hierarchical relations are usually based on service ontology of the systems [61, 62, 127, 198, 199] or domain ontology [90, 175].

The dynamic part is usually modelled with rule-based modelling approaches when the delivery of services is related to the context. User preference introduced in [54, 98, 131] relates the context to user desired services. User preference models in these applications are modelled with unrelated preference items and, as a consequence, it is not easy to organize and manage these relations if there are many. Moreover, because these rule-based models do not consider relating personalized service structure to the user's decision tree [137], if the user's desired services under the current context have been removed, it is difficult for the system to recommend alternative services to the user without interruptions.

Sources of user profile

In literature, there exist three approaches [100, 118] for creating user profiles:

(1) Users create their own profiles. However, letting users input their information explicitly must consider the acceptance of the user. Some of the user profile information items such as the user's gender and the date of birth can be input explicitly by the user by filling in member application forms or questionnaires once at the system level. However, it is hard to let the user input his/her preference at the event level frequently.

(2) Systems are in charge of creating the profiles. With the development of the technology it is possible to gather user profile information implicitly [156]. Krause [99] presented a context-aware mobile phone application in which the context-dependent preferences were learned by identifying individual user states and observing how the user interacts with the system in these states. This learning process occurs online and does not require supervision. The system relies on the techniques from machine learning and statistical analysis. Romero described a recommender system that uses web mining techniques for recommending a student personalized links within an adaptable educational hypermedia system [93, 156, 157].

(3) The mixed approach of above. Some information of the user profile is entered explicitly by the user and some is learned implicitly by the system. For example, user demographic (date of birth, gender, nationality) information and user interests can be entered by the user explicitly, whereas the context-dependent user preference is learned by the system implicitly.

Biosignals are often collected from the users using a variety of sensors to reflect the status of the user in a particular context [196, 197]. In this thesis, heart rate is investigated as an example to get insights how the biosignals could play a role in adaptive entertainment systems, and the music recommendation system in particular. Next we try to shed some light on the relation between the music and the heart rate.

2.3.3 Relation between music and heart rate

There are a few studies in literature that investigate the relation between the heart rate and the music tempo. Sleight [21] found that listening to music with a slow or meditative tempo has a relaxing effect on people, slowing breathing and the heart rate. Listening to faster music with a more upbeat tempo has an opposite effect - speeding up respiration and the heart rate. Allinder et al. [7] reported similar results. The effects of different types of music on the heart rate were experimentally tested in [12], where it was discovered that 100% of the subjects' heart rates increased when they listened to fast tempo music. Iwanaga [81] found that people prefer music with the tempo ranging from 70 to 100 per minute which is similar to that of adults' heart rate in normal daily situations.

Research has showed that the heart rate can be used as an indicator of stress. Nancy [49] found that during exams and when their graded results were returned to them, the heart rate of most students increased substantially. Taelman [191] reported that a person's heart rate is significantly faster when the person is in mental stress. If one is in an excessive physical stress state, it may fatigue one's heart and cause bradycardia, or a slow heart rate [101].

There is a long literature list involving the use of music for reducing stress. Miluk-Kolasa et al. [124] showed that music was one of the relaxing adjuncts in modulating the ascent of autonomic responses to negative stress. Knight and Rickard [92, 212] reported that relaxing music attenuated blood pressure and heart rate after a stressful task; moreover, the level of anxiety was reduced after listening to relaxing music. The tempo of the music being listened to is an important parameter [92]. Steelman [41, 179] investigated a number of studies of music effect on relaxation. He concluded that music items with tempos of 60 to 80 BPM reduce the stress and induce relaxation, while music items with tempos between 100 and 120 BPM stimulate the sympathetic nervous system. White and Shaw [41, 205] reported similar results. They found that tempos slower than the average human's heart rate (40 to 60 BPM) induce suspense, while tempos of 60 BPM are the most soothing. Stratton [182] concluded that there is a significant correlation between degree of relaxation and preference for music. User preference, familiarity or past experiences with the music have an overriding effect on positive behavior change.

2.3.4 Cybernetics control systems

According to Heylighen and Joslyn (page 2 of [67]), "Cybernetics is the science that studies the abstract principles of organization in complex systems. It is concerned not so much with what systems consist of, but how they function. Cybernetics focuses on how systems use information, models, and control actions to steer towards and maintain their goals, while counteracting various disturbances. Being inherently transdisciplinary, cybernetic reasoning can be applied to understand, model and design systems of any kind: physical, technological, biological, ecological, psychological, social, or any combination of those."

A simple cybernetics control system (figure 2.7) consists of a feedback cycle. It has two inputs: the goal and the disturbances. The goal represents the expected values of the system's essential variables. The disturbances are all the processes in the environment that the system does not have under control but that can affect these variables [67].

Once started, the system begins to observe or sense the variables that it wishes to control. After these variable values are acquired and an internal representation is created, the information in the representation is processed in order to determine: 1) whether it can affect the goal? If it can, then, 2) what is the best strategy to secure that goal. The system then decides on an appropriate action after the information processing. This action affects some part of the environment. Through the normal causal processes or dynamics of the environment, other parts of the environment are also affected. These dynamics are influenced by the disturbances. This dynamical interaction affects other variables which are observed by the system. The change in these variables

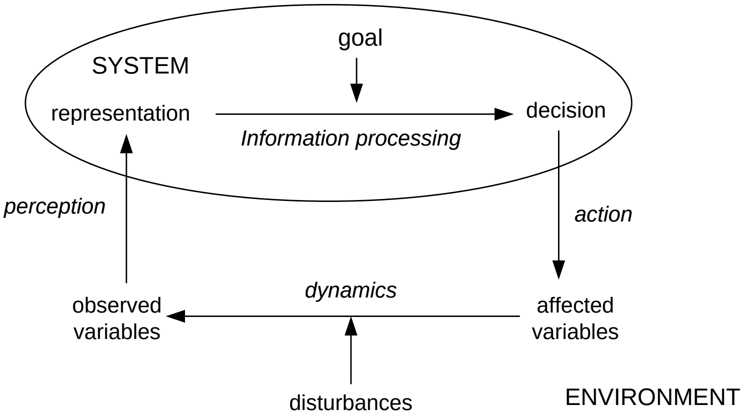


Figure 2.7: Basic components of a cybernetics control system, taken from [67] page 16.

is again acquired and an internal representation is created. This again triggers interpretation, decision and action process. The control loop is closed [67].

2.3.5 Stress model

Stress occurs when the demands of a situation outweighs the body's or mind's ability to cope with it [9,26]. Research suggests that some segments of the working population are at a higher risk of physical and mental stress than others. These segments include health care industry, fire fighting, military, police, software industry, and call centers [37, 69]. Examples of daily job scenarios where physical stress is induced are repetitive motions and postural distortions for a long period of time. Mental stress is induced by the scenarios such as impossible deadlines, lack of sleep and family financial crisis. High levels of physical and mental stress could lead people to adverse physiological conditions. These negative conditions include elevated blood pressure levels, increased heart rate, excessive sweating and higher intake of oxygen. Among them, the heart rate is extremely sensitive to different kinds of stress [32]. For instance, a repetitive physical task requires sustained strength and endurance. The body responds by increasing the heart rate. It is of interest to investigate how physical and mental demands can affect the heart rate or heart rate variability. The remaining question is how to measure them correspondingly.

Heart rate variability

The heart rate variability (HRV) is the variations of the beat-to-beat alteration in the heart rate. HRV analysis is widely used to assess the effect of autonomic nervous system regulation on the heart rate [84, 119].

The autonomic nervous system is a regulatory branch of the central nervous system that helps people adapt to changes in their environment. It is composed by two subsystems: the parasympathetic nervous system and the sympathetic nervous system. They operate in the reverse of the other (antagonism). The autonomic nervous system provides a dynamic nature of the interplay between the sympathetic and parasympathetic branches [57].

The sympathetic nervous system is the fight-or-flight branch of the autonomic nervous system. It is essential during emergency situations. The activation of the sympathetic nervous system causes the increase of the sympathetic branch activity that accelerates the heart rate, constricts blood vessels, and raises blood pressure [57].

The parasympathetic branch induces the relaxation response that slows down the heart rate, increases intestinal and gland activity, relaxes sphincter muscles and decreases the force of the heart's contractions [57].

There is a balance between the parasympathetic nervous system and the sympathetic nervous system under normal situations, placing the body in a state of homeostasis. However, under a state of mental stress, this balance will be altered [146]. Hence, HRV can be used to detect the change in system balance and this change can be used as an indicator of the mental stress [22]. HRV has also been used in clinical research to assess the prognosis of different pathologies in several cardiological and non-cardiological diseases such as myocardial dysfunction, diabetes and arrhythmias [119].

The QRS complex (R peak) (figure 2.8) of ECG reflects the electrical activity within the heart during the ventricular contraction [97]. It also reflects the other contractions and the corresponding relaxation phases. QRS complex needs to be detected to generate RR intervals (figure 2.8) that represent the time periods between consecutive heartbeats. These RR intervals can be used for time based and frequency based HRV analysis [23, 144]. However, an accurate QRS complex detection may be difficult due to the physiological variability of the QRS complex and various types of noise that can be present in the ECG signal [134, 161]. Typical noise artefacts in ECG signals are power line interference, electrode contact noise, motion artefacts, and baseline drift [59].

Analysis of heart rate variability

According to the standards set forth by the Task Force of the European Society of Cardiology and North American Society of Pacing and Electrophysiology in 1996 [119], there are two methods for HRV analysis: time-domain and frequency-domain.

In the time domain, the analysis methods include SDNN, RMSSD, NN50 count. SDNN is the standard deviation of all RR intervals. The RMSSD index is defined as the root mean square of the differences of the successive RR intervals. The NN50 count is the number of adjacent RR intervals differing more than 50 ms. Decreased HRV has been associated with the mental stress in lab experiments. If the condition is long lasting, it may lead to cardiovascular diseases [69]. Resting had a positive effect on HRV and blood pressure.

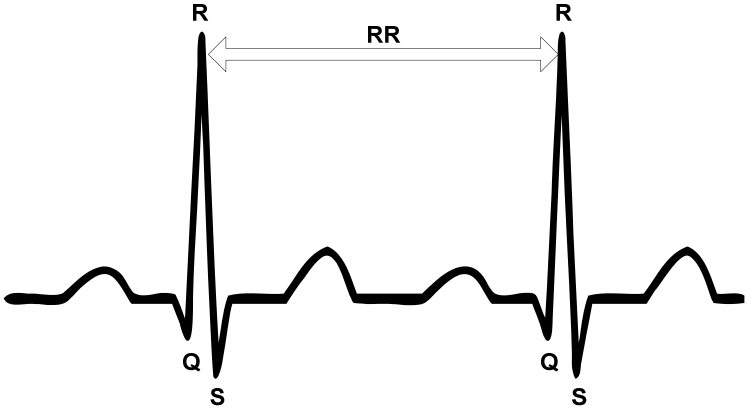


Figure 2.8: Heart rate variability: R peak and RR interval

Intermittent rest periods between various physical and mental tasks showed an improvement in HRV [69].

HRV is comprised of multiple frequencies. Frequency domain methods analyse the waveform by looking at the different frequency components. The two main frequency components that represent the autonomic nervous system activity are the low frequency (LF) components (0.04 to 0.15Hz) and the high frequency (HF) components (0.15 to 0.4 Hz).

LF is associated with blood pressure control, reflecting sympathetic activity. Its power increases when the person is in high strain conditions. For instance, the power under LF increased significantly when posture was changed from supine to standing [85]. Exercise showed an increase in the LF component compared to non-exercise [213]. HF is correlated with respiratory sinus arrhythmia reflecting parasympathetic activity [84]. The HF power for trained individuals is more than that for untrained individuals [86, 133].

The LF/HF ratio is used to indicate the balance between the sympathetic and parasympathetic systems. A decrease in this score might indicate either increase in the parasympathetic system or decrease in the sympathetic system. In [37], user experiments showed that LF/HF ratio and residual heart rate increased in the high job stress group during work days.

Comparing the frequency-domain analysis to the time-domain analysis, the disadvantages of the time-domain analysis method are twofold: (1) it needs more data (long time) analysis to be accurate than the frequency-domain analysis; (2) since HRV value is sensitive to age, gender, and posture, etc., frequency-domain based LF/HF ratio is a more accurate indicator of stress than time-domain based absolute HRV value.

To summarize, mental stress occurs when we feel unable to deal with high demands placed upon us. When this happens, the balance between the parasympathetic nervous system and the sympathetic nervous system is disrupted. The

LF component of HRV is associated with the sympathetic activity. It becomes high when the person is in high strain conditions. The HF component is an indicator of the parasympathetic autonomic response. It is reduced during heavy exertions and awkward postures. The ratio of LF to HF (LF/HF) can be used as an index of the parasympathetic and sympathetic balance. When the ratio is high, it is correlated with high strains.

2.4 Summary

In this chapter, the current in-flight music systems were investigated. Contemporary in-flight music systems are designed as user adaptive systems. They present passengers with the same interface and contents. Passengers need to input their requirements step by step to explicitly acquire music services. It is hard for them to find preferred music items either because of too many options and too much interaction, or too few options.

The current music recommendation methods are reviewed. They are categorized into content-based filtering, collaborative filtering, context-based filtering and hybrid music recommendation methods. In each category, the rationale for the method was reviewed and its applications were explored.

Finally, in this chapter, enabling technologies are investigated. They include context-adaptive system, user profiling, cybernetic control system, relation between music and heart rate, and stress model. In the next chapters, these technologies were utilized to design and evaluate the heart rate controlled music recommendation system.

Chapter 3

Framework

This chapter presents the design of an adaptive framework for the heart rate controlled in-flight music recommendation system. Based on the context-based and content filtering recommendation methods, it integrates several concepts into a discrete event based feedback system [159], including context adaptive systems, user profiling, and the methods of using music to adjust the heart rate and reduce the stress. The feedback control loop includes sensors for measuring passenger's heart rate, modules for acquiring and modeling heart rate signal, and an adaptive control unit that integrates the music adaptation strategies and the system-user interaction components. They are coordinated to regulate passenger's heart rate at normal level thus reduce the stress through heart rate awareness and personalized music recommendations.

The rest of this chapter is organized as follows. A user scenario is introduced in section 3.1 to highlight both user interaction and system behavior. Based on this scenario, the objectives of the system are derived and described in section 3.2, after that the adaptive framework and the details of each component of the framework are presented in section 3.3. Conclusions are drawn at the end.

3.1 User scenario

This scenario was defined in the context of the SEAT project to communicate the objectives and the concepts to the partners [117].

> In order to foster the customer loyalty, in addition to offering the frequent travelers the rewards such as bonus miles, speedy services, and free hotels, the airline SEAT offers passengers the rewards of "additional services" such as personalized in-flight entertainment. To get the access to these extra services, the passenger needs to apply a club member card from SEAT.
>
> Mr. John Smith is a frequent air traveler. He always flies with SEAT. In order to get the "additional service" from SEAT, he applied to

be a club member of SEAT. He had filled out the membership application form which asked for his name, gender, date of birth, music preferences. After SEAT received and approved his application form, his personal data was input into SEAT's in-flight entertainment system database. Now, when Mr. John Smith buys a flight ticket from SEAT and later selects a seat number online or at the check-in desk, his profile will be linked to his in-seat entertainment system.

During the long haul flight, when Mr.John Smith sits in the seat, his heart rate is measured non-intrusively by the heart rate sensor embedded in the seat textile. If his heart rate is higher than normal and he wants to listen to music, the system will recommend him a personalized music playlist which can down-lift his heart rate back to the normal. If Mr. John Smith's heart rate is normal and he wants to listen to music, the system will recommend him a personalized playlist which helps to keep his heart rate at normal; if his heart rate is lower than normal and he wants to listen to music, the system will recommend a personalized playlist that can uplift his heart rate back to normal. If Mr. John Smith does not like the recommended music, he can decline it and manually reselects the music he likes. During this process, the system logs his interactions. The system can then learn and adapt to his latest music preferences. The result of the recommendation will be then influenced by the status of the heart rate as well as his preferences. By using the heart rate controlled music recommendation system during the flight, Mr. John Smith gets less stress and his comfort level is improved.

3.2 Objectives of the system

As described in the user scenario, the objectives of the system are (1) to reduce the passenger's stress during the flight; (2) to uplift, down-lift the passenger's heart rate back to normal with music if it is abnormal; (3) to help keeping the passenger's heart rate at normal with music if it is normal. The system achieves these objectives by mediating among the passenger's heart rate, the music preference and the available music items to recommend personalized playlists to the passenger. In figure 3.1, the explicit input include the passenger's personal information filled out in the club member application form, and the input directly from the user interface, e.g. pressing a button to start or stop the music service. The implicit input includes heart rate and adapted music preferences as well. The adapted preferences are based on the explicit input in the application form and the user interaction in accepting and rejecting the recommended music.

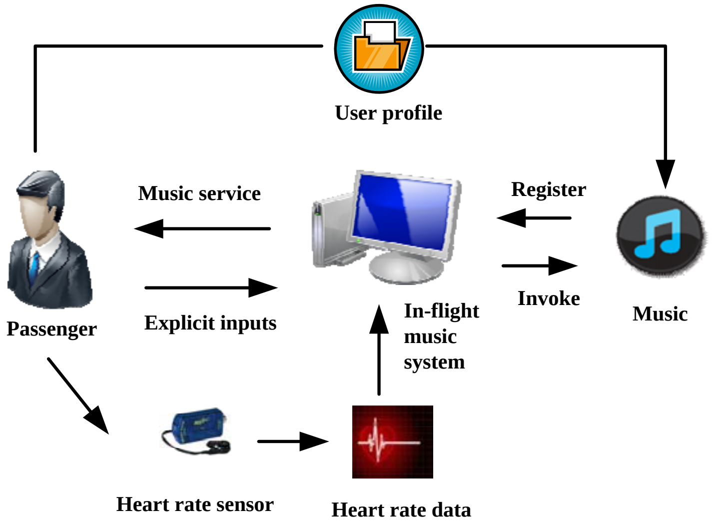


Figure 3.1: In-flight music system mediates between heart rate, preference and music

3.3 Framework

The framework starts by observing passenger's current heart rate and creating an internal representation of the passenger's heart rate situation. The information in this representation then must be processed in order to determine whether the passenger's heart rate is normal. If it is, the adaptive inference recommends a list of personalized keeping music to keep the passenger's heart rate at normal according to the user profile. If the passenger's heart rate is faster/slower than normal, the adaptive inference recommends a personalized down-lifting or uplifting music playlist according to the user profile. User profile includes the passenger's demographic and music preference information. This information can be filled in explicitly by the passenger when he/she applied for a club card.

If the adaptive inference recommends the music items that one does not like, one can reject the recommendation and reselect the music item oneself. During this process, the system logs the interaction between the passenger and the system. By mining on the log information, the user preference learning component can learn the passenger's latest music preferences and update the music preference information in the user profile. Figure 3.2 illustrates the design of the system framework.

The working procedure of the framework is as follows. If the passenger wants to listen to recommended music playlists, he/she starts the system. The adaptive inference runs the music recommendation procedure to recommend the passenger personalized uplifting/keeping/down-lifting (arousal/neutral/calming

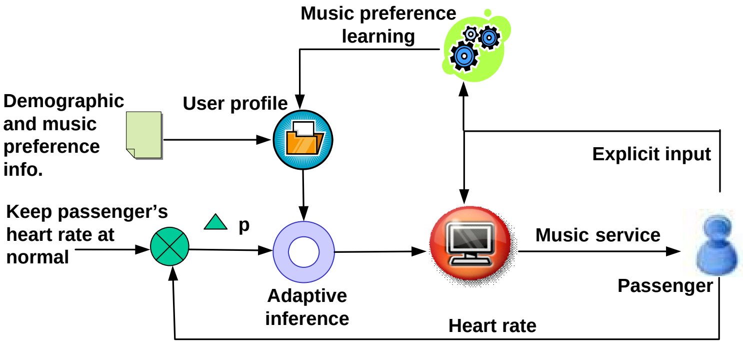


Figure 3.2: In-flight music system framework

[89]) music playlists. Then, the passenger interacts with the system to accept or decline the recommendation. At the same time, the system logs the interactions. The logged information is used for the passenger's latest music preference learning. The learned results are forwarded to the user profile to update the music preference items. Figure 3.3 delineates the working procedure of the framework.

Next the main components in the framework, their working procedures and the coordination among them will be described in detail.

3.3.1 Heart rate

The heart rate is the number of heartbeats per unit of time - typically expressed as Beats Per Minute (BPM). A simple method of measuring heart rate is to count the pulse of the body per minute. This pulse rate can be measured at any point on the body where an artery's pulsation is transmitted to the surface [109]. A more precise method involves the use of ECG measurements. The heart rate is the inverse of RR interval (see figure 2.8).

Everyone has a normal heartbeat rhythm. A normal heart rate is the number of times the heart beats per minute when a person at rest. For a baby (age 0-6), the normal heart rate is 90-110 BPM. For a child (age 6-18), the normal heart rate at rest is 70-100 BPM. For an adult (age 18 and over), the normal heart rate at rest is 60-100 BPM [109].

If the heartbeat rhythm is disrupted and is beating lower than the normal heart rate, it is called bradycardia. Bradycardia may be caused by a pre-existing heart disease, the natural process of aging, or stress [101]. It may cause tiredness, dizziness, breathlessness, blackouts, and if severe enough, death. This occurs because the person with bradycardia may not be pumping enough oxygen to the heart and other vital organs, which may cause heart attack-like symptoms.

We write $\mathbf{HR}_{min}$ to denote the minimal heart rate of an individual. The ever recorded $\mathbf{HR}_{min}$ of a healthy human is 28 BPM [109].

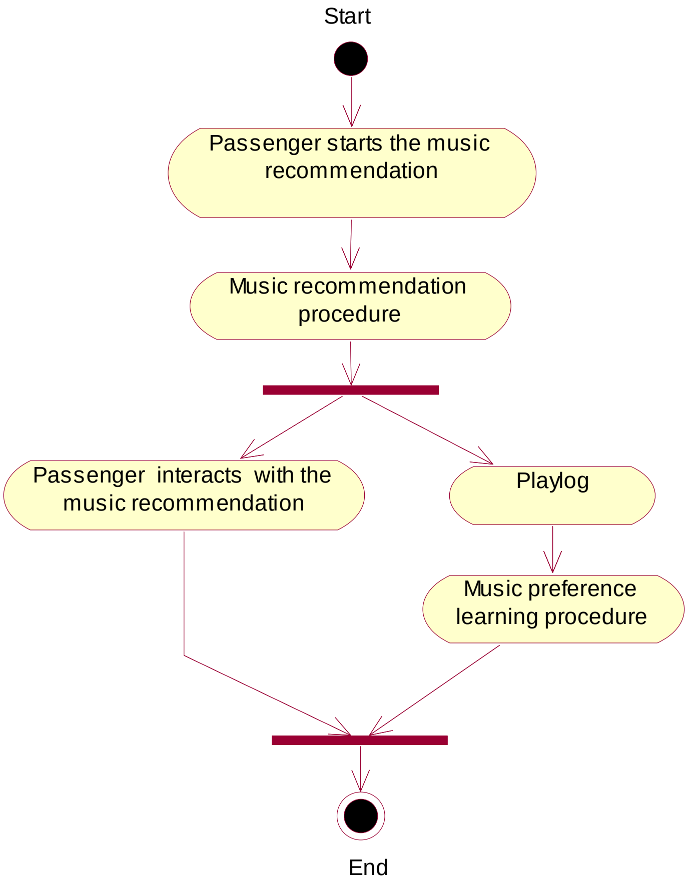


Figure 3.3: In-flight music system working procedure

If a person's heartbeat rhythm is abnormal and is beating higher than normal, it is called tachycardia. When the heart beats rapidly, every heart beat pumps less efficiently and provides less blood flow to the rest of the body, including the heart itself. It is a normal response to excitement, anxiety, stress, or exercise. A fast heart beat causes shortness of breath, dizziness, fainting, chest pain, severe anxiety, and even a heart attack if it persists. This occurs because the decreased flow of the necessary amount of oxygen to the heart causes myocardial cells to begin to die off [102].

We write $\mathbf{HR}_{max}$ to denote the maximal safe heart rate for an individual. Various formulas are used to estimate $\mathbf{HR}_{max}$, based on the age, but $\mathbf{HR}_{max}$ varies significantly among individuals. The most common formula encountered, with no indication of standard deviation, is [109]:

Age	Bradycardia	Normal	Tachycardia
18-	28-59	60-100	101-202
6-18	28-69	70-100	101-214
0-6	28-89	90-110	111-220

Table 3.1: Heart rate ranges in BPM for three age groups [109]

$$\mathbf{HR}_{max} = 220 - age \tag{3.1}$$

In this thesis, the heart rate is modeled with three states: tachycardia, normal and bradycardia. For each age group, they have different heart rate ranges (table 3.1).

3.3.2 Digital music and metadata

Music is an art form consisting of sound and silence [122]. Elements of sound in music include pitch, rhythm, and the sonic qualities of timbre and texture. It is created by artists to express emotions, feelings and thoughts. Music nowadays can be recorded, stored, transferred, and played back in an audio file in a digital format. Currently, there are tens of these formats, such as mp3, wma, wav and ogg. In this thesis, mp3 is adopted. It is the most popular format for downloading and storing music and is supported by most of the digital music players.

Music metadata is usually part of the music file that is used to describe the characteristics of the music. ID3 [79] is a metadata container used in conjunction with the mp3 audio file format. It allows information such as the title, artist, album, track number, tempo or other information about the music piece to be stored together in the file.

Currently, there are two unrelated versions of ID3: ID3v1 and ID3v2 [79]. After the creation of the mp3 standard, a problem occurred regarding with storage of the information about the raw data in a file. Standalone mp3s do not have any special method of doing this.

In 1996 Kemp had the idea to add a small chunk of data to the audio file, thus solving the problem. The standard, now known as ID3v1, quickly became the de facto standard for storing metadata in mp3s. The ID3v1 tag occupies 128 bytes, beginning with the string TAG. The tag was placed at the end of the file to maintain compatibility with older media players. The fields include the title, artist, album, year, comment, track, and genre.

In 1998, a new standard called ID3v2 was created to increase the description power of the music metadata. ID3v2 tags are of variable size, and usually occur at the start of the file, to aid streaming media. They consist of a number of frames, each of which contains a piece of metadata. For instance, the TBPM frame contains the BPM, the TIT2 frame contains the title, and the WOAR frame contains the URL of the artist's website. There are standard frames for containing BPM, title, genre, and artist, as well as other things. The BPM in ID3v2 helps to store and retrieve the information about the music tempo, which is important for the system to find proper piece of music to uplift, keep or down-lift the user's heart rate. ID3V1 and ID3V2 defined 126 music genres. In ID3V2, these genres of the music can be further refined with sub genres. Figure 3.4 delineates the music meta data information in ID3V2.

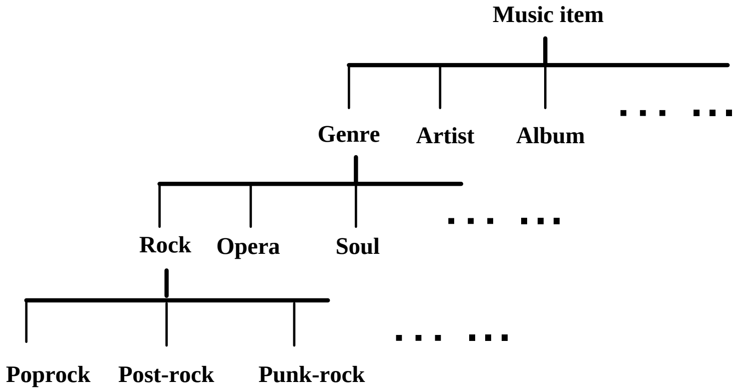


Figure 3.4: Music metadata information in ID3V2

3.3.3 User profile

The user profile includes the passenger's demographic information and music preference. User demographic information includes items such as name, date of birth, gender etc. By the date of birth, the passenger's age can be simply computed. This information is used by the system to determine the age dependent normal heart rate ranges (table 3.1). User's music preference is the user's long term evolving commitment to certain categories of music. It is composed of preference items such as jazz, rock, pop genres of music that the user likes [115]. This information is used by the system to personalize the music recommendation. In order to model the user profile, some formal definitions needed, which are given as follows.

Definition 1: User's demographic information is a set of attribute/value pairs,

$$D = \{(da_1, dv_1), (da_2, dv_2), ...(da_n, dv_n)\} \tag{3.2}$$

in which (da_i, dv_i) is the i_{th} attribute/value pair, $i \in 1..n$.

Definition 2: A piece of music item is described by a set of attribute/value pairs:

$$M = \{(a_1, v_1), (a_2, v_2), ...(a_n, v_n)\} \tag{3.3}$$

where (a_i, v_i) is the i_{th} attribute/value pair, $i \in 1..n$.

Definition 3: User's music preference is a set of preference items,

$$P = \{P_1, P_2, ..., P_n\} \tag{3.4}$$

in which the i_{th} item P_i $(i \in 1..n)$ is defined as an attribute/value pair with a weight to the value:

$$P_i = (a_i, w_i * v_i) \tag{3.5}$$

where the attribute is a_i and its value is v_i, w_i is the weight of the music preference item. (a_n, v_n) is an element of M.

Definition 4: The user profile is then defined as a tuple of the demographic information and the music preference of the user:

$$U = (D, P) \tag{3.6}$$

Based on above definitions, an object oriented model is derived (figure 3.5). A user's profile model is composed of the demographic information and the music preference. the music preference is composed of a set of preference items. Each preference item is represented by an attribute/value pair. It can be further refined into sub preference items. User demographic information is composed of a set of information items. Each item is represented again as an attribute/value pair.

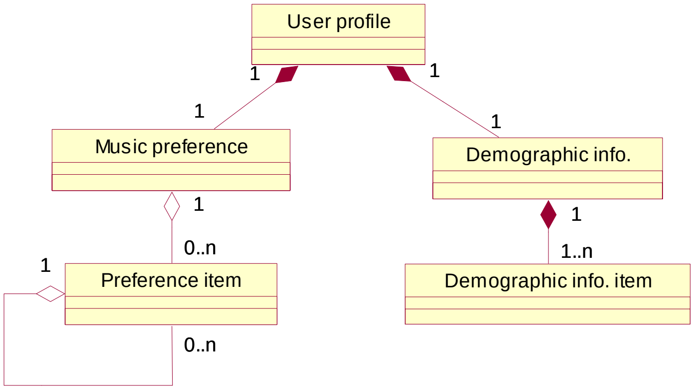


Figure 3.5: User profile model

Rentfrow (page 1241 of [141]) found that "when people discuss their music preferences they tend to do so first at the level of genres. Then, they talk to lesser extent subgenres. Only later, they step up to broader terms (e.g., loud) or down to specific artists (e.g., Van Halen) or songs (e.g., "Running with the

Devil")" . In the implementation of this work, the genre is the level at which the system starts the investigations of music preference.

The passenger's demographic information is input explicitly by the passenger when applying for the membership card from Airline SEAT. In the Air SEAT club membership application form (see appendix A), the users need to fill out their names, gender, and date of birth. The users can also indicate to which extent they like the fourteen popular music genres [141] in the form. The extent to which they like the music is translated into the weight of the music preference item, on a scale of 1 to 7. "like" is translated into 1 and "like strongly" is translated into 7. The music preference items (weight*genre) indicated by the passenger explicitly are then used for music recommendation to avoid the "cold start" problem. If the passenger is not willing to indicate his/her music preference explicitly, the music preference will be learned by the system implicitly.

3.3.4 Adaptive inference

The adaptive inference component is the central part of the framework. It mediates among the user's heart rate, the user profile, and the music to recommend personalized music playlists to keep the user's heart rate at normal thus reduce the stress.

The adaptive inference component works with the ECA (Event-Control-Action) mechanism, that is, when the event occurs, if the condition is verified, then the action is executed [172]. It receives the events (e.g., the passenger wants to listen to music) from the user and reacts on the personalized music recommendation controlled by the user's current heart rate.

If the passenger wants to listen to music during the flight, the adaptive inference component acquires the user profile and the current heart rate. According to the user's age it determines which state the user's heart rate is in (see table 3.1) and decides upon the playlist to be recommended accordingly.

If the user's heart rate is in a tachycardia state, the system recommends a down-lifting personalized music playlist to transfer it back to normal; if the user's heart rate is in a bradycardia state, the system recommends an uplifting personalized music playlist to uplift it back to normal; otherwise, if the user's heart rate is in a normal state, the system recommends a personalized keeping music playlist to keep it at normal (figure 3.6).

If the passenger declines the recommendation, the system provides functionalities for the passenger to browse and select preferred music items to compose a music playlist manually.

Next the music recommendation method used in the framework is introduced, as well as, refinement of the composition of the music playlist and the interaction between the user and the system.

Filtering

The music recommendation method used in this framework is a hybrid method that combines context-based and content-based filtering recommenda-

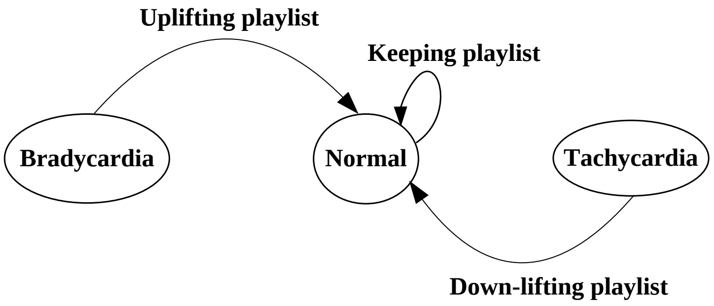


Figure 3.6: Heart rate state transfer with music playlists

tion approaches. There are two reasons why the collaborative filtering is not used. First, long haul flight passengers come from highly heterogeneous user groups such as culture and nationalities. Second, according to Stratton [182], there is a significant correlation between the degree of relaxation, and the music preferences and past experiences of the user, hence content-based filtering approach works better for the user and for the purpose of relaxation than the collaborative filtering approach. Content-based filtering approach is used to match the recommendation to the user's music preference, while context-based music filtering recommendation approach is used to adapt the music to the user's current heart rate.

The recommendation process starts with content-based filtering to acquire a sub collection of music items. The context-based music method then takes over to filter the acquired music collection. Figure 3.7 delineates the detailed recommendation process.

During content based filtering, the adaptive inference component first gets the user preference items and orders them into a stack in descending order of the given weights. If the stack is not empty, the filtering continues with the preference item to be popped from the stack. After that, a collection of music items is acquired. If the collection is not empty, it is forwarded to the next phase of context-based filtering. If it is empty, the adaptive inference component gets the preference item from the top of the stack and repeats the procedure until the stack is empty.

The context-based filtering starts with determining which state the passenger's current heart rate is in and the size of the playlist. The heart rate state is based upon user's date of birth, current heart rate and the age related heart rate normal range (see table 3.1). The size of the playlist is based upon the value of the heart rate, heart rate state and the passenger's normal heart rate range.

Later in the project when the framework was implemented, a design decision was made on the size of the playlist. If passenger's current heart rate is in the bradycardia state and its value is less than or equal to the upper limit value of

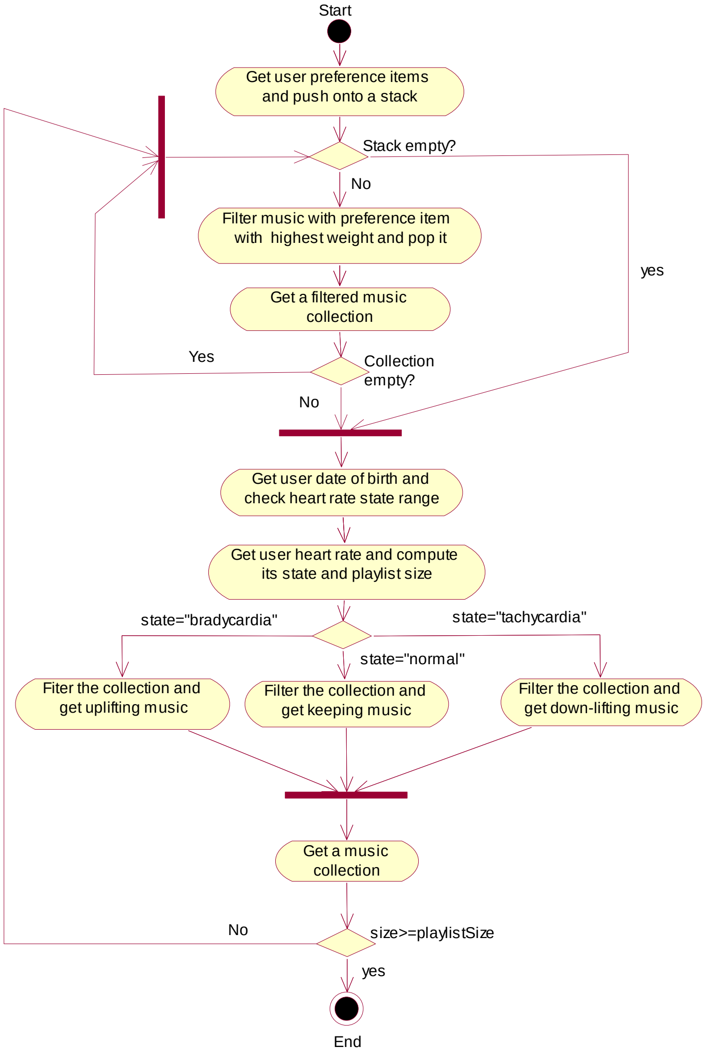


Figure 3.7: Music recommendation procedure

the bradycardia minus 5 (e.g., for adult, 55 BPM), the size of the playlist is 12. Or, the size of the playlist is 6. The size of the music playlist is fixed to 12(6) because we want a playlist listening time ranging from approximately 30(15) minutes to approximately 40(20) minutes. If the passenger's heart rate is in the normal state, the size of the playlist is 12. If the passenger's current heart rate is in the tachycardia state and its value is greater than or equal to the lower limit value of the tachycardia minus 5 (e.g., for adult, 95 BPM), the size of the playlist is 12. Or, the size of the playlist is 6. This is rather a design decision based on common sense rather than solid arguments. What is the optimal size of the playlist remains as a question for future research.

If the passenger's current heart rate is in the bradycardia state, the system selects music items with a tempo among 100-120 BPM to uplift the user's heart rate back to normal. According to [179], music with a tempo between 100 and 120 BPM stimulates the sympathetic nervous system and speed up the listener's heart rate. If the passenger's heart rate is in the normal state, the system selects music items which BPM is in the normal range of the user's heart rate (see table 3.1). According to [81], people prefer music items with tempo similar to that of adults' heart rate under normal daily situations. If the passenger's current heart rate is in the tachycardia state, the system selects and recommends music items with a tempo from 60 to 80. According to Steelman [179], tempos of 60 to 80 BPM have a relaxing effect on people, slowing breathing and heart rate.

After the context-based filtering, the selected music collection is refined. If the size of the collection is smaller than the music playlist size, the adaptive inference component goes back to the content based filtering and repeats the procedure until the collection size is equal to or bigger than the music playlist size.

Refinement

The filtered music collection is now ready for refinement to fit the size of the playlist. For the convenience the filtered music collection is denoted by M, and the size of the playlist is denoted by m.

If the user's current heart rate is normal, the next step is simply to select music items with tempos within the passenger's normal heart rate range from the collection to fill up the playlist. If the user's heart rate is in a bradycardia or tachycardia state, the next step is to further refine the selection. The objective of the refinement is when the user's heart rate is in a bradycardia or tachycardia state, the system recommends an uplifting/downlifting music playlist to transfer the user's heart rate back to normal with the minimum time cost (see figure 3.6). Markov decision process (MDP) is used to refine the filtered music collection to compose a refined music playlist.

The objective of the MDP is to select m pieces of music items among the filtered music collection M. These m pieces of music items not only enable the heart rate to transfer from the bradycardia or tachycardia states to the normal state but also enable the adaptive inference to get the maximum rewards. The less time spent on transferring from bradycardia or tachycardia states to the normal state, the more reward is received. Adapted to this context, an MDP is defined as follows.

Definition 5: An MDP is a 4-tuple $(S, A, P.(.,.), R.(.,.))$, in which

- S is a finite set of all possible heart rate states,

$$S = \{s_b, s_n, s_t\} \tag{3.7}$$

  where s_b, s_n and s_t represent the state of bradycardia, normal and tachycardia respectively.

- A is a finite set of actions:

$$A = \{a_i | i \in M\} \tag{3.8}$$

  where a_i is the action that one particular piece of music i from the collection M takes to enable the passenger's heart rate state transition.

- $P_a(s, s')$ is the probability that an action a taken by a piece of music would transfer the heart rate state s at the time τ to the heart rate state s' at the time τ':

$$P_a(s, s') = \mathbf{P_r}(s_{\tau'} = s' | s_\tau = s, a_\tau = a) \tag{3.9}$$

  where $s \in S, s' \in S$, and $\tau' > \tau$.

- $R_a(s, s')$ is the reward received after transition to the heart rate state s from the heart state s_i with the transition probability $P_a(s, s')$. The negative value of the amount of the time needed for this transition is taken as the reward. The less the time it takes, the more the reward is received.

Based on this definition, the refinement of the filtered music items is transferred to an MDP problem: to find a function to maximize the rewards with that the adaptive inference component will receive to transfer the bradycardia or tachycardia state to the normal state. The function takes the current heart rate state as input and tries to find a playlist L that contains m music items from the collection M that maximizes the rewards:

$$f(s) = \arg\max_L \sum_{i \in L} P_{a_i}(s, s_n) R_{a_i}(s, s_n) \tag{3.10}$$

in which $L \subseteq M, \#L = m$ and $s \in S \setminus \{s_n\}$. To be more clear, the domain of f is $\{s_b, s_t\}$, and the range of f is $\{L \mid L \subseteq M \wedge \#L = m\}$.

When the user's heart rate is in a bradycardia state, the functionality of f is to compose a music playlist with size m among the filtered music collection M to uplift the heart rate to the normal state with the maximum rewards. According to [21, 44], listening to faster music with a more upbeat tempo speeds up heart rate. So the refinement of the music collection M is to sort the music items and select m pieces of music items with a faster tempo to fill up the playlist.

When the user's heart rate is in a tachycardia state, the functionality of f is to compose a music playlist with size m among the filtered music collection M to down-lift the heart rate to the normal state with the maximum rewards. Again, according to [21, 44], listening to music with a slower tempo slows down the heart rate. Tempos of 60 BPM have the most soothing effect [205]. In this case the refinement of M is to sort the music items and get m slower ones to fill up the playlist.

3.3.5 Interaction

One of the important principles of designing user-system interaction is that the user must feel and actually be in control [149]. It is identified by [46] as one of the most important principles to be taken into account when designing a more comfortable aircraft cabin interaction space for passengers. It means that passengers are aware of things that are going on during the interaction and they should not feel lost or confused. They shall be confident that everything is under control. Three measures are identified by the author to ensure that users are in control of the interaction processes: (1) they should be able to use and exit the system at any time; (2) they should be able to accept and decline the recommendations; (3) they should be able to browse and select preferred music items to compose a music playlist manually if they decline the recommendation.

Interaction with the system can be either explicit or implicit. Implicit input is for example heart rate gathered by the sensor. Explicit input is for example passengers expressing their needs to the system by explicit input such as pressing a button and filling out the profile forms. System output is for example music recommendation and playback. The output is the system's response to the passenger's explicit and implicit input. The interaction is depicted in Figure 3.8.

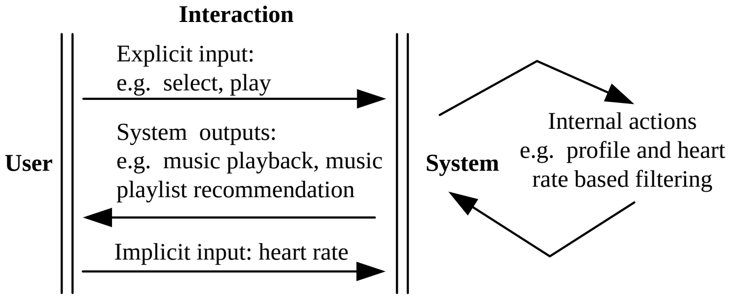


Figure 3.8: Interaction between the user and the system

During the flight, if passengers want to listen to music, they can explicitly start the system by pressing a button. Once the system is started, it uses both the passenger's heart rate and the user profile to recommend music. The passengers can then accept the recommendation and listen to the music playlist, but can also stop and exit the system at any time by explicitly pressing on the exit button or other buttons that lead to other parts of the system (for example, movies and games).

If a passenger declines the recommendation, the system provides the functionalities of a normal music system. The passenger can browse through the options in terms of artists or albums, and select the desired music items to manually compose a playlist. When the passenger listens to the self-selected music items, the system logs this information for learning the passenger's music preference.

3.3.6 User preference learning

In the user profiles, the music preference items are either given by the passengers when they filled out the membership application forms, or later learned by the system by mining on the interactions between the passengers and the system.

The learning process adopts the method of "relevance feedback" to capture an appropriate snapshot of the user's interests in the music. Relevance feedback has been employed in several types of systems for the purpose of personalization [66, 70, 96, 160, 203]. Relevance feedback approaches are based on either an explicit or implicit feedback gathering scheme. In the explicit feedback gathering scheme, users provide the object ratings of predefined scales. In the implicit feedback gathering scheme, object ratings of predefined scales are inferred by mining on user interactions with the system in a transparent fashion.

Explicit Ratings. Explicit ratings is a common phenomena in our daily life. It scattered from grading students' work to assessing consumer products. Some of the ratings are made in free text forms. More ratings are made on an agreed discrete scale (e.g. star ratings for restaurants, marks out of ten for films, etc) [42].

Passenger's music preference can be collected by explicit rating. However, the passenger has to examine the provided items and decide a value on the rating scale. This imposes cognitive and behavioral cost on the passenger [42].

Implicit Ratings. Implicit relevance feedback gathering techniques are proposed as unobtrusive alternative or supplement to explicit ratings. Click-throughs and time spent viewing a document are among the possible sources of implicit feedback [42]. The system can thus monitor the user interaction to estimate the user preference.

Compared to explicit rating, the main benefits of implicit rating include: (1) removal of the cognitive cost of relevance judgments on the objects explicitly; (2) can be gathered in large quantities, then aggregated to infer item relevance.

Two types of music preference can be learned by the implicit relevance feedback: (1) the music preference about which the user did not give the answers in the questionnaire (see appendix A). In ID3, there are 126 genres of music in total, which makes it very tedious if the user is asked to rate on every of them; (2) user's latest music preference shown via the interaction with the system during the flight.

User's feedback on the recommendation can be implicitly captured by logging the interaction between the user and the system. The logged information includes the music items played and declined. Data structures of the log information are defined as follows.

Definition 9: A piece of music that has been played LM_n is logged as

$$LM_n = (t_{mark}, m_n) \tag{3.11}$$

where t_{mark} is the time the user started to listen to the music item m_n.

Definition 10: A piece of music that has been declined LDM_i is logged as

$$LDM_i = (t_{mark}, m_i, d) \tag{3.12}$$

where t_{mark} is the time the user declined the recommended music item m_i and d is the declination mark.

The working procedure of the music preference learning is as follows. Once a piece of music item was played or declined, the system acquired the genre of the music item and check whether there is a music preference item in the user profile with the same genre. If it has and the music item was played, the weight of the music preference item adds 0.1, if it has and the music item was declined, the weight of the music preference item minus 0.1; if it has not and the music item was played, a new music preference item is created where the weight is one and the genre is the played music item genre, if it has not and the music item was declined, a new music preference item is created where the weight is zero and the genre is the declined music item genre. After learning, the system updates the music preference items in the user profile. Figure 3.9 illustrates the working procedure of the music preference learning.

3.4 Summary

This chapter introduces a user scenario which highlights the functioning of the heart rate controlled in-flight music system. Based on this scenario, the objectives of the system are defined: The system should mediate among the user's heart rate, user profile and music to: (1) keep the user's heart rate at normal; (2) reduce the passenger's stress during the flight. Then the user's heart rate and the user profile are modeled. After that, the music metadata adopted in this thesis is described. The user's heart rate is modeled with the states of bradycardia, normal and tachycardia. When the heart rate is in either bradycardia or tachycardia state, it means that the user's heartbeat rhythm is disrupted. The user profile is modeled with both the demographic information and the music preference. Music metadata is described with ID3.

The design of the system framework is presented. Based on context-based and content-based filtering methods, the framework integrates the concepts of

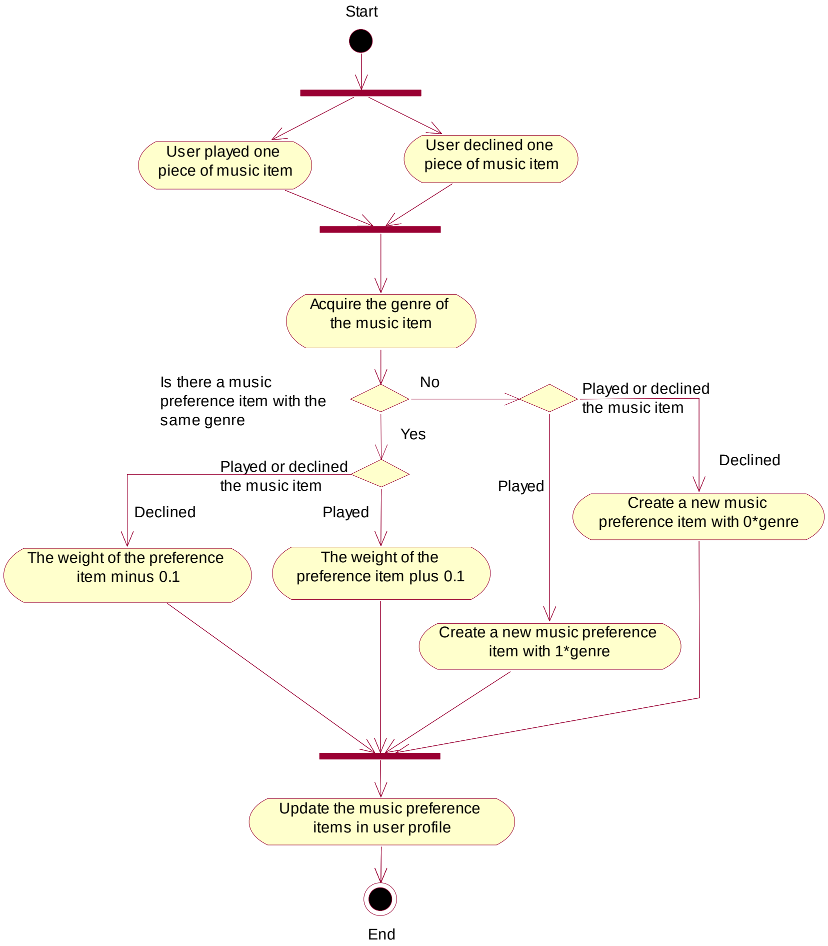


Figure 3.9: Music preference learning procedure

context adaptive systems, user profiling, and the methods of using music to adjust the heart rate in a feedback control system. The framework recommends a heart rate adaptive and personalized playlist to the users. If the user's heart rate is in a bradycardia or tachycardia state, the framework recommends an uplifting or down-lifting music playlist to the user respectively. By listening to the recommended music, the user's heart rate can be transferred to normal with the minimum time cost and the stress can be reduced. If the users decline the recommendation, they can select preferred music tracks manually to make a desired playlist. During this process, the system logs the interaction between the user and the system. The logged information is used for updating the user's latest music preference.

Next chapter has more about the implementation of the framework presented in this chapter.

Chapter 4

Implementation

This chapter presents the software architecture that was designed and implemented to realize the system framework for the purpose of proof of concept and experiment. The design is based on component-based software engineering, which emphasizes the separation of concerns of the wide-ranging functionality [140]. The software architecture has five abstraction levels. At each level, components are designed to support a part of the functionalities of the framework. The layers and the components in layers are loosely coupled, which would increase the flexibility of the software architecture. The software architecture is implemented using Java [189], MySQL [45], Jamon [82] and Javascript [56] with a client/server structure. The implementation is based on an open source software Sockso [176] which provides a good foundation for a client/server structured music player. The software is designed to be installed on an on-board server, delivering the content to in-seat computers over an intranet. The in-seat client provides a browser based interface for the passenger to interact with the service.

In this chapter a platform independent software architecture and its implementation are presented first, followed by the details of the simulation environment in which the software is installed and tested.

4.1 Software architecture

There are five abstraction layers in the designed software architecture. At the bottom layer is the resource layer. It serves the upper layers with music items, heart rate signals (from the sensors) and the user profile.

The second layer is the resource manager layer. It includes the managers of the resources: the music manager, the heart rate manager and the user profile manager. The music manager is responsible for synchronizing the information about the available music on the physical storage to the corresponding data in the database, including managing the process of registration and deregistration. The heart rate manager collects the signal readings from the sensors, stores and updates heart rate information in database. The user profile manager collects and updates the passenger's demographic information and music preference.

The third layer is the database layer. It not only acts as a data repository, but also decouples the layers and the components in these layers. For example, replacing or updating components in the resource manager layer would not affect the rest of architecture as long as the corresponding data structures used to store data in the database are kept intact.

The fourth layer contains the adaptive control units. It includes the component that logs the passenger's feedback and interaction, the component for learning user preference, as well as the adaptive inference component. The log component is responsible for logging passenger's feedback to the recommended music into the database. The learning component is responsible for learning user's music preference based on the logged feedback and interaction. It forwards the learning results to the database and updates the user music preference. The adaptive inference component is the core component. It is used to mediate among the user profile, the heart rate data and available music items to recommend personalized and heart rate controlled music playlists. The fifth layer is the graphical user interface. This is the only layer to which the users have access. Figure 4.1 shows the designed software architecture. Next the design and implementation of each component in it are described in detail.

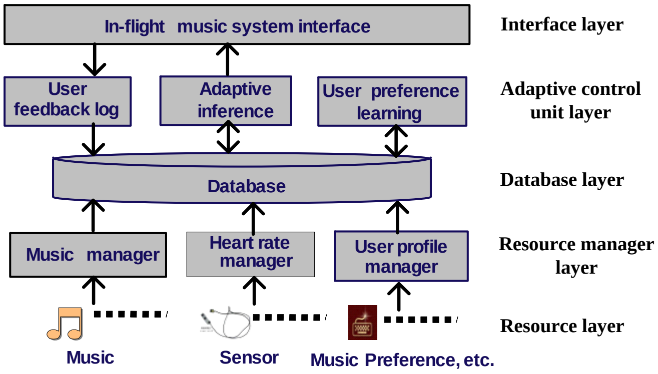


Figure 4.1: Software architecture

4.1.1 Music manager

The functionalities of the music manager include registration/ deregistration of the music items to the system and displaying registered music items to an interface for management. The registration process is to extract music metadata automatically from mp3 files and import the metadata into the database. Deregistration is to remove the selected music metadata from the system if the corresponding music items are not present in the file system.

The music registration component has functions to import a music collection,

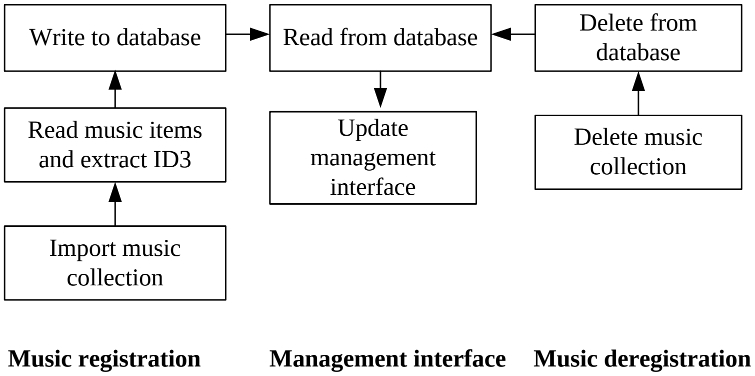


Figure 4.2: Music manager overview

read the music items in the collection and extract ID3 information from these items and write the metadata into the database (figure 4.2). The registered music metadata is used for later select on and recommendation of music.

When importing a music collection, the system administrator is provided with an interface to preview it and decide whether and which items to import (see figure 4.3)[1]. Once selected, the collection's name, path information is immediately acquired. After that, the music items' path information is acquired and their ID3 metadata information is extracted. The acquired and extracted information is then written to the collection and tracks tables in the database (for details of the collection and tracks tables, please refer to subsection 4.1.4). At the same time, the music manager reads and updates the album and artist information in the database. Figure 4.4 is the class diagram of a collection, track, album and artist[2]. The music manager is programmed according to the class diagram to read the acquired and extracted information and write it to the database.

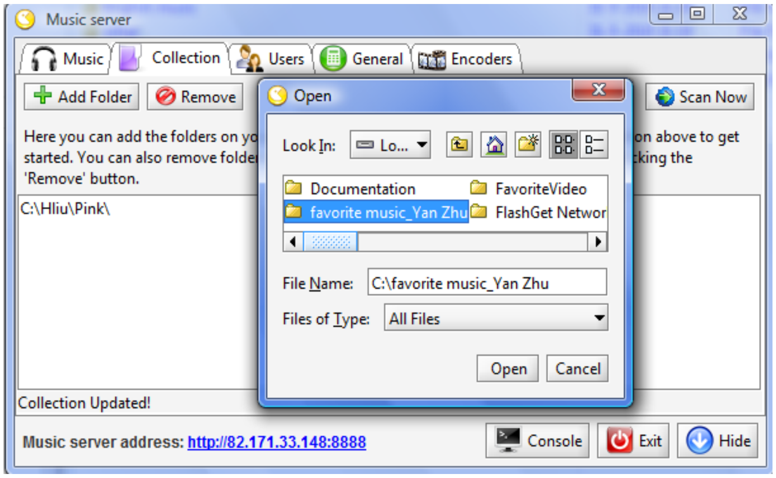
The management interface provides access to the functionalities for managing the music items imported. It reads the information from the database and presents a list of music items to the system administrator to facilitate the managerial tasks. The system administrator can browse the registered music tracks with artist and album names.

From the management interface, the system administrator can perform deregistration to remove certain music metadata from the database and to remove the music items from the file system. The music manager is implemented in

---

[1] The screen captures look similar to the original Sockso, but they are improved and adopted for the heart rate controlled music system, especially the underline data structures and algorithms are redesigned. This holds for all the screen captures of the management interface presented later.

[2] This structure is designed based on the structure from source code of Sockso, with necessary additions to support the information related to the heart rate and the user preference, i.e. BPM and genre.



Here you can add the folders on yo
started. You can also remove folde
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king the

C:\Hliu\Pink\

File Name: C:\favorite music_Yan Zhu

Files of Type: All Files

Collection Updated!

Music server address: http://82.171.33.148:8888

Figure 4.3: Import the music collection

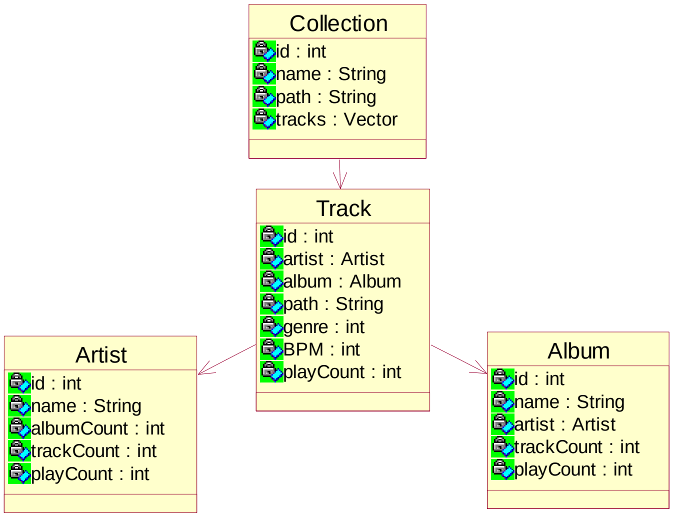
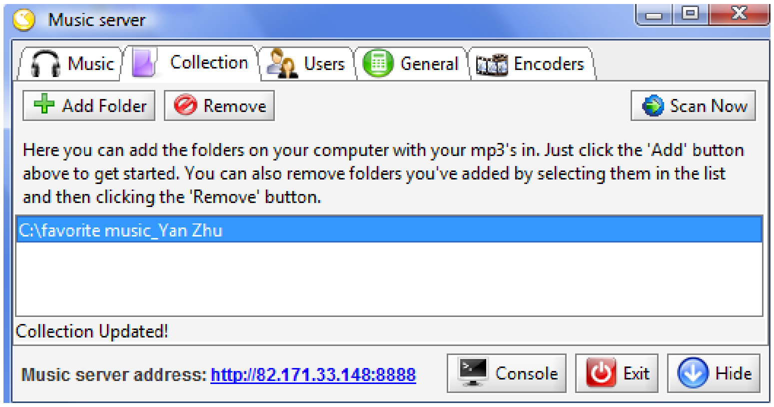


Figure 4.4: Collection, track, album, artist

Java. The class CollectionPanel is designed to implement music registration and deregistration. The method addCollectionFolder of CollectionPanel can be used to import music collections. It provides the system administrator with the dialogs to add a new music collection (figure 4.3) from a folder in the file system. The method addCollectionFolder then reads the address of the selected folder and passes it to the method parseFolder. The method parseFolder reads music items and extracts ID3v1 and ID3v2 metadata. The features extracted include the information about artist, album, file name, file path, genre, publish year, BPM and track number. The method writeToDatabase takes the result and writes it into corresponding tables in the database. Music deregistration functionality is implemented with the method removeCollectionFolder and the method deleteFromDatabase, removing the music items from the file system and music metadata information from the database. In figure 4.5, after selection, the system administrator clicks on the "remove" button and the selected music collection is deregistered from the system.



Here you can add the folders on your computer with your mp3's in. Just click the 'Add' button above to get started. You can also remove folders you've added by selecting them in the list and then clicking the 'Remove' button.

C:\favorite music_Yan Zhu

Collection Updated!

Music server address: http://82.171.33.148:8888

Figure 4.5: Updating the music collection

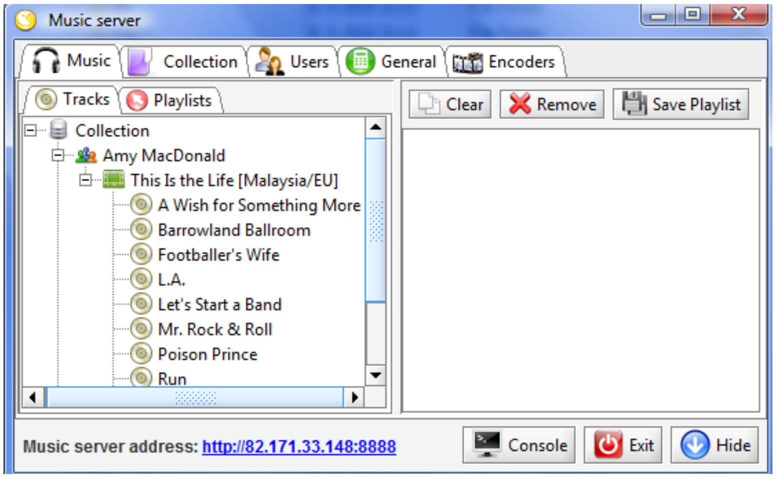
The class MusicPanel implements the management interface. It creates a panel to list the registered music items. The list is presented as a three layer artist-album-track structure for the system administrator to explore the collections (figure 4.6).

4.1.2 Heart rate manager

The heart rate manager is responsible for collecting heart rate data from the sensors and storing it to the database. The implementation of the heart rate manager depends on the type of the heart rate sensors selected.

Heart rate sensor. The long-haul flights are typically non-stop journeys on a wide-body aircraft, over a long distance, often beyond six and a half hours in travel time [121]. To increase the effect of the music on the passenger's heart rate, the distractions caused by anything in between should be reduced to a minimum. The most important principle of invisibility in the field of pervasive computing [164] applies here: The selected heart rate sensors and the related sensing technology should be completely erased from the passenger's in-flight life during the long-haul flight, leaving only the interface for the passenger to interact with the multimedia content instead of the technology thus minimizing the distractions from the technology behind.

In the literature, various heart rate sensors have been used for the heart rate measurement and heart rate variability analysis. The most popular ones are



Music server address: http://82.171.33.148:8888

Figure 4.6: Imported music management interface

various ECG monitors (e.g., ECG monitor MD100A1, Polar RS800 monitor. See figure 4.7 and 4.8). However, for these ECG monitors to work, ECG electrodes must be attached to the body of the user. The monitors record ECG signals from the electrodes. The heart rate value is the inverse of RR intervals. In figure 4.7, ECG monitor MD100A1 stores ECG records by attaching three ECG electrodes on the body of the user. In figure 4.8, Polar RS800 records the ECG signal by putting a strap around the user's chest. These two typical ECG sensors must attach something directly to the user's body, which are totally impractical for the long-haul flight passenger's heart rate measurement.

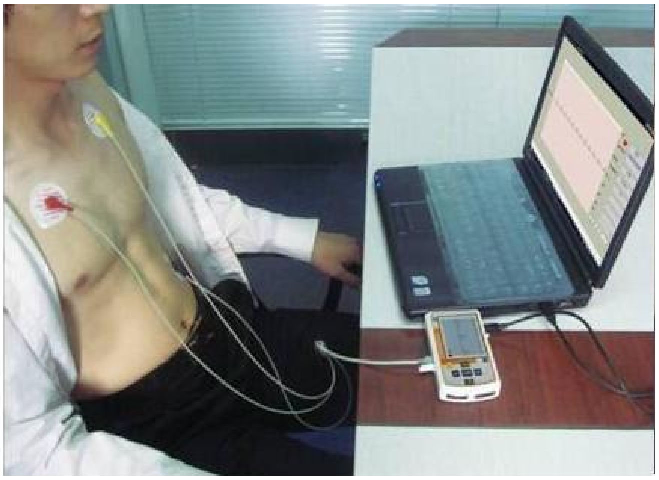


Figure 4.7: ECG monitor MD100A1 (this photo is taken from MobiKorner [125])

Figure 4.8: Polar RS800 monitor (this photo is taken from Polar [143])

Instead of the sensors just mentioned, the Emfit bio sensor (figure 4.9) is chosen. The Emfit bio sensor is developed by EMFIT [51], a research company. It is not yet available on the market. After TUE and EMFIT signed an official NDA (Non Disclosure Agreement), Technical University of Eindhoven purchased several Emfit bio sensors from EMFIT for the purpose of research and experiment.

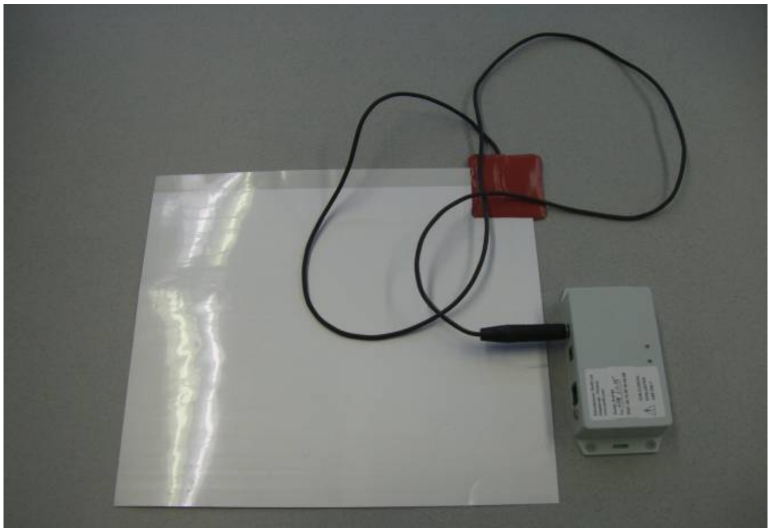


Figure 4.9: Emfit heart rate sensor

The Emfit bio sensor consists of two parts: a sensor film and a processor. The core competence is the innovative Emfit film, which is unique and provides strong electromechanical response. “It is based on a polyolefin material manufactured in a continuous biaxial orientation process that stretches the film in two perpendicular directions (machine direction and transverse direction). The structure of Emfit film consists of flat voids separated by thin polyolefin layers. The Emfit film is 70-80 μm thick. The voids are made by compounding small particles, which function as rupture nuclei and form closed lens-like cavities to the film during the biaxial orientation.” [50]

According to the page one of Emfit film specifications [52], “The bi-axially oriented film is further swelled with high-pressured gas injection technology. The swelling process more than doubles the thickness and elasticity of the film by increasing the size of air-voids inside it. Electromechanical response with properly swelled cellular film is over twofold compared to when the film is charged before swelling. Operating in a reciprocal fashion, changes in the thickness of the Emfit sensor generate a corresponding charge and hence, the electrode is charged as well. The transducer behaves like an active capacitor.” Figure 4.10 is the operation principle of Emfit film.

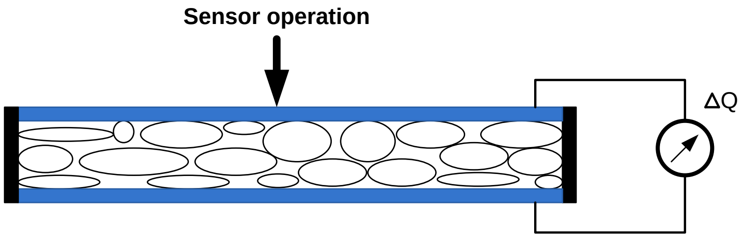


Figure 4.10: Operation principle of the Emfit film (adapted from [52])

When the user sits on the Emfit film, the Emfit processor acquires electrical signals from the Emfit film. It processes these electrical signals and computes the user’s heart rate. The processor outputs the result through a 3V level serial port. The data connection to a computer is made through FTDI TTL-232R-3V3 (RS part no. 429-307). It connects to a USB port and is then available as virtual com port (VCP) for the computer’s operating system. The Emfit processor sends the real time heart rate data to the computer every second [3] .

The heart rate manager is programmed using Max/MSP 5.1 [39]. It receives the data stream from the VCP and decodes it according to the protocol provided by EMFIT. The decoded heart rate data is stored in the heartrate table of the database.

The Emfit film is placed non-intrusively under the passenger’s seat cover

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[3] For this project, EMFIT released the protocol for reading the heart rate data from the received signals to TU/e. Because of the signed NDA, the details of the protocol cannot be presented here.

(figure 4.11). It is connected to the processor attached under the passenger's seat. The processor is connected to the in-seat computer. After the heart rate manager is activated, it receives the passenger's heart rate data from the Emfit processor. When the passenger sits in the seat, he/she is unaware of the sensor. The heart rate measurement is hidden from the passenger.

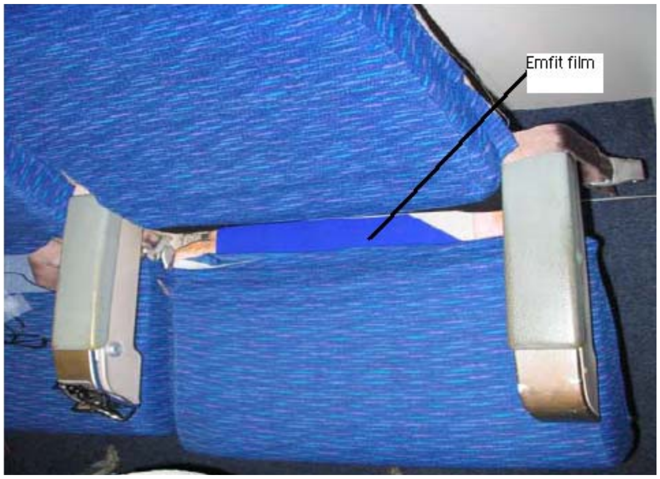


Figure 4.11: Emfit sensor is embedded in the seat

4.1.3 User profile manager

The main functionalities of the user profile manager are to register and deregister users to and from the system, and provides a management interface for the system administrators to manage the user profiles (figure 4.12).

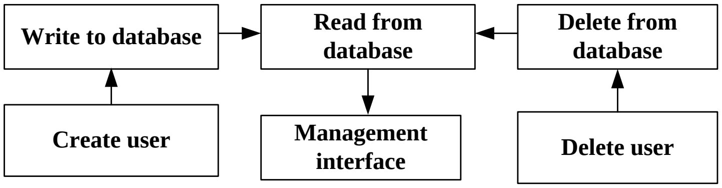
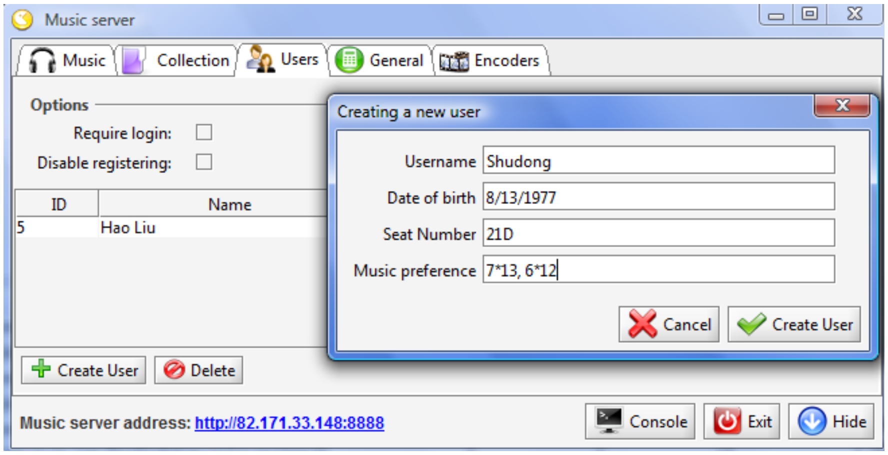


Figure 4.12: User profile manager overview

The user profile manager is implemented in Java. The class UserPanel has the methods getAccountsPane, deleteSelectedUser and refreshUsers to fulfil the functionalities of the user profile manager. The method getAccountsPane creates the main pane with the user account controls (figure 4.13). If the system administrator clicks on the "Create User" button, the class CreateUserDialog is initialized and a dialog pane pops up for the system administrator to input user's name, date of birth, seat number and music preference. The music preference is used by the system administrator to input music preference items filled in by the passenger when he/she applied the club card. Each music preference item is composed by the passenger preferred music genre and its weight. It is expressed as weight*genre. The music preference items are separated by commas. The class UserPanel then uses the method getUserInfo to read the data from the panel and write it to the user table in the database. Each user is assigned with a unique ID. In figure 4.13, 6 and 7 are the weight of the preferred music genres. 12 and 13 are the music genre codes in ID3. The music preference items are separated by a comma.



Options

Require login: ☐

Disable registering: ☐

ID	Name
5	Hao Liu

Username: Shudong

Date of birth: 8/13/1977

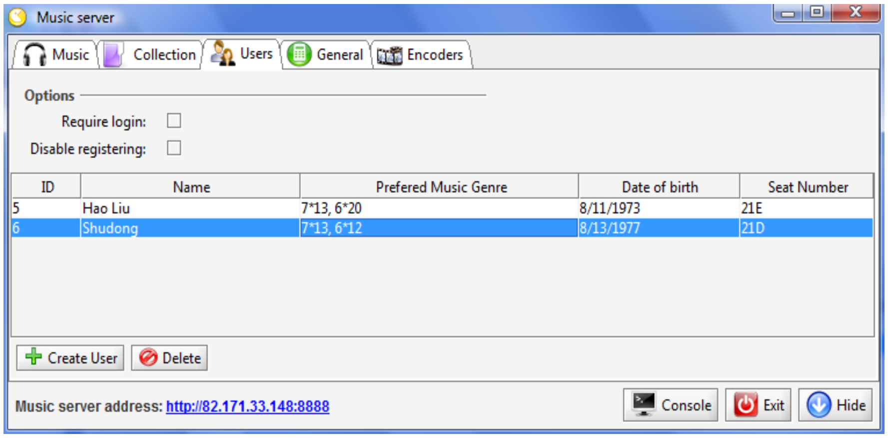
Seat Number: 21D

Music preference: 7*13, 6*12

Music server address: http://82.171.33.148:8888

Figure 4.13: Create a user profile

The method refreshUsers reads the registered user information from the database and refreshes the user list on the management interface (figure 4.14). The method deleteSelectedUser fulfils the user deregistration functionality. It deletes the selected user profile from the database. In figure 4.14, the system administrator can press the “Delete” button to remove selected user profile from the database.



Options

Require login: ☐

Disable registering: ☐

ID	Name	Prefered Music Genre	Date of birth	Seat Number
5	Hao Liu	7*13, 6*20	8/11/1973	21E
6	Shudong	7*13, 6*12	8/13/1977	21D

Music server address: http://82.171.33.148:8888

Figure 4.14: User management interface

4.1.4 Central data repository

The system uses the industry standard MySQL database to store the data. A seat schema is created in MySQL, which contains the following tables: album, artist, heartrate, collection, playlist, play_log, playlist_track, track and user. Figure 4.15 is the schema's entity-relation diagram. The system uses Java Database Connectivity (JDBC) APIs to connect the database for access.

4.1.5 Adaptive inference

The adaptive inference is the core component of the software architecture. It is implemented in Java. The class AdaptiveInference is designed to implement the adaptive inference process described in chapter two. It has getUserInfo, getUserHeartrate and getMusicTracks methods to read user profile, the heart rate and the metadata of the music items from the database. Its getRecPlaylist method mediates among them to recommend heart-rate controlled and personalized music playlists to the user. Once AdaptiveInference is initialized, its construction method invokes these methods to realize the adaptive inference process.

In AdaptiveInference, there is also a savePlaylist method to store the recommended music playlists to corresponding tables in the database. The playlists table stores the recommended music playlists (figure 4.15). The information for the related music items is stored in the playlist_tracks table (figure 4.15).

4.1.6 User feedback log

The log component logs user's feedback to the recommended music playlists for learning user's latest music preferences. The music items played and declined are logged in the table play_log (figure 4.15).

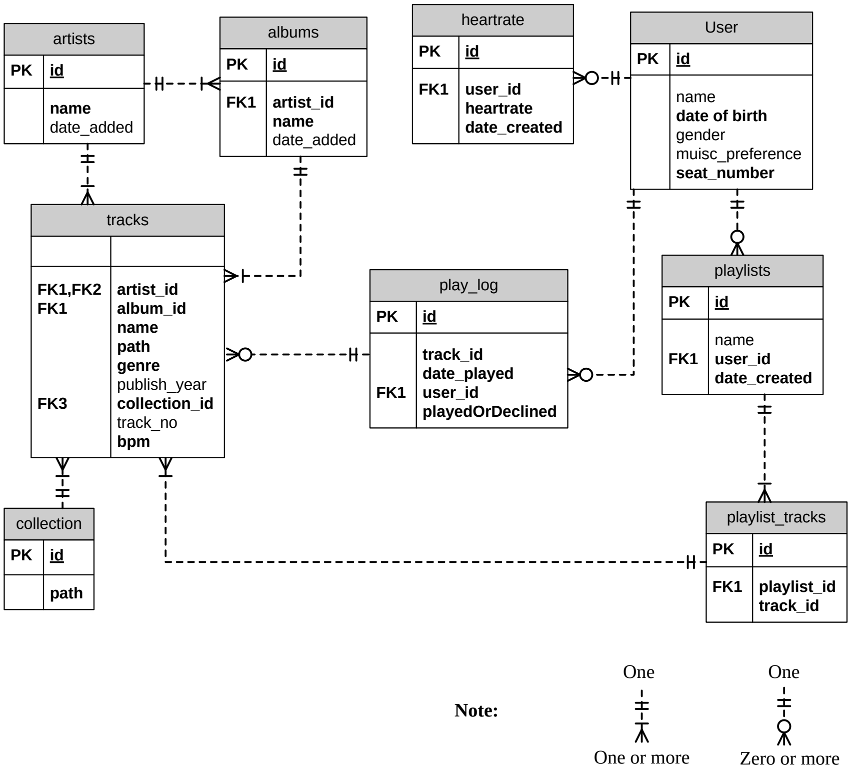


Figure 4.15: Entity-relation diagram

4.1.7 User preference learning

The user preference learning component is implemented in Java. The class PreferenceLearning is designed to implement the algorithm described in section 3.3.6 of chapter 3. Its userPreferenceLearning method implements the learning algorithm to learn the passenger's music preference. Also, PreferenceLearning has the method savePreference to save and update the learned results to the user profile.

4.1.8 Interface

The user interface component supports the interaction process presented in section 3.3.5 of chapter 3. It is implemented with the Jamon [82] engine. Jamon is a text template engine for Java applications. It is convenient and useful for generating dynamic HTML, XML, and any other text-based content. In a typical Model-View-Controller architecture [53, 73], Jamon aims clearly at the View (or presentation) component.

Several templates are designed for Jamon to generate HTML based interface.

The template TMain.jamon is designed to define the layout of the interface page. The template Tplaylist.jamon is for the presentation of recommended music playlists. TArtist.jamon and TAlbum.jamon templates are designed to dynamically present the available artists and albums in the database. During the process of interactions between the user and the system, dynamic HTML interface pages are generated by the composition of these templates. The process of using dynamic HTML pages to create the user interface is described next.

4.1.9 Interaction between the user and the system

The interaction between the user and the system is based on a Client-Server model. The Client-Server model is a distributed structure that partitions tasks or workloads between service providers, called servers, and service requesters, called clients [190]. The software architecture in figure 4.1 specifies the functionalities designed in the system framework. It provides the system functionalities (services) simultaneously to many clients (in-the seat computers for the on-board passengers) that initiate requests for such services.

An HTTP server is implemented to receive the request from the user and respond to the requested functionalities. The class HttpServer is designed to create an instance of the http server (figure 4.16). It runs in its own thread to start the server and keep it running. It uses a broker object httpRequest to listen to user requests and to response with an httpResponse. Its "shutdown" method stops the running thread and shuts down the server. The object httpRequest reads and processes an http request. Its process method uses methods readStatusLine, readBody and readHeaders to process requests from input streams. The object httpResponse carries the responses to user requests. It uses the showHtml method to generate the requested HTML page by dynamically composing templates such as Tmain.jamon, Tplaylist.jamon, TArtist.jamon.

The class HttpServer needs to be bound to an IP address with a port number in order to listen to incoming Transmission Control Protocol (TCP) connections from the clients at this address. The method getHost binds the http server to the local computer IP address where the system is installed. The default listening port is set to 6666. The method getPort is defined for the system administrator to change the port number in case of port 6666 being used by other applications. In figure 4.17, the method getHost reads the host IP address and the method getPort reads the new port number 8888 defined by the system administrator. The host IP address and the port number together form the music server address and is displayed on the control panel.

The interaction between the user and the system starts by the HTTP requests being initialized and sent to the server. Having received the request, the server uses the method showHtml to generate a main HTML page based on the TMain.jamon template. On the client side, the passenger is presented with the interface by rendering the HTML page. In figure 4.18, the iHeartrate [4]

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[4] iHeartrate is the alias name of heart rate controlled music recommendation system. It comes from "i heart rate".

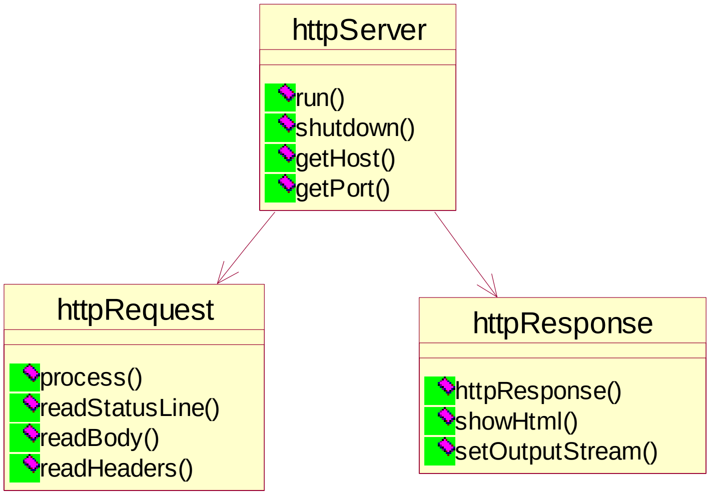
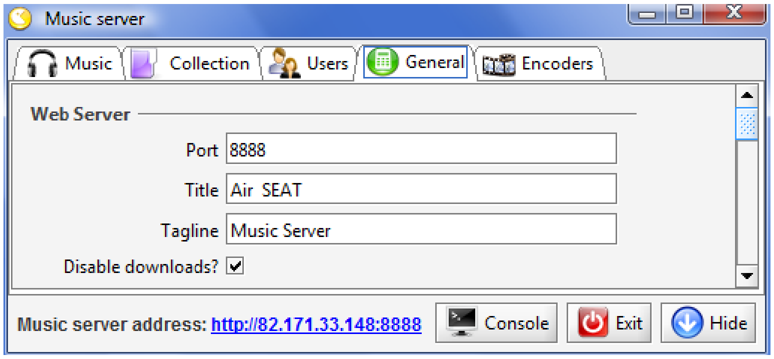


Figure 4.16: Class diagram of http server, which implements the API from Sun Microsystem [188]



Web Server

Port 8888

Title Air SEAT

Tagline Music Server

Disable downloads? ☑

Music server address: http://82.171.33.148:8888

Figure 4.17: System music server

Music Recommendation hyperlink leads to the heart rate controlled music recommendation system. The Movies, Games and Music hyperlinks lead to other entertainment systems respectively.

To listen to recommended music, the user may click on the iHeartrate Music Recommendation hyperlink. An http request is then sent to the server and the server will dynamically compose an HTML document based on the templates TPlaylist.jamon and TMain.jamon. The template TPplaylist.jamon uses a java program to invoke the adaptive inference to start heart rate controlled and personalized recommendation. Figure 4.19 shows the interface of the heart rate controlled music recommendation system. In this figure, because the user's cur-

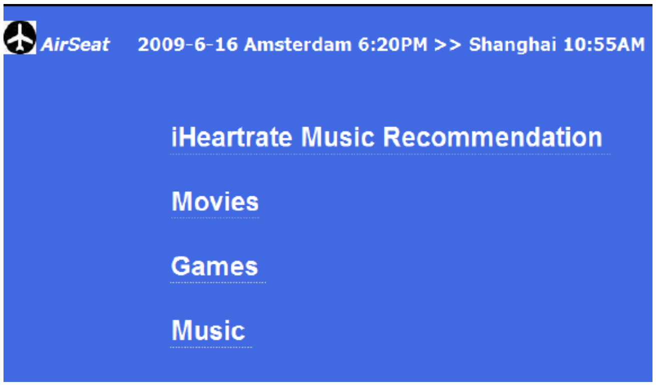


Figure 4.18: In-flight entertainment top level screen

rent heart rate is normal, the system recommends a personalized relaxing music playlist. The passenger can activate the hyperlink relaxPlaylist and receive the detailed music items. If the user's current heart rate is in a tachycardia or bradycardia state, the interface changes accordingly and recommends either an uplifting or a down-lifting music playlist respectively.

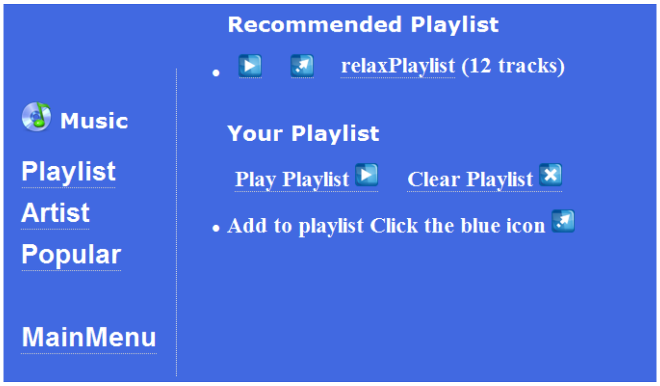
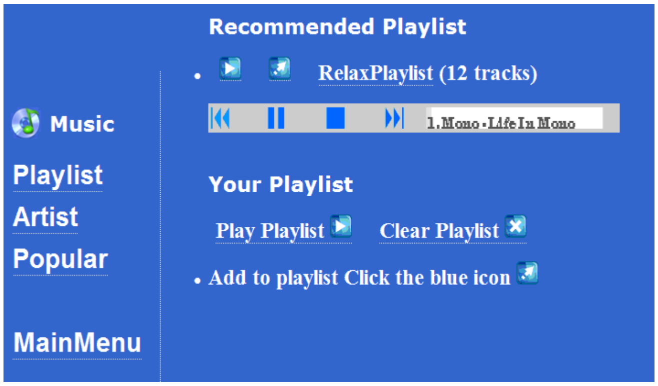


Figure 4.19: Music system interface

The user may click on the Play icon ▶ to start the music player. A javascript program, player.js, presents an open source XSPF web music player (flash) [218] on the interface and plays the recommended music playlist (figure 4.20).

The user may ignore the recommended list and click on the links Artist and Popular to select favorite music manually. A similar request-response process creates the corresponding interface. In figure 4.21, the interface presents the available artists from the database. If any of them is preferred, the user can press the button ↗ to add all the music items from the preferred artist to the playlist. A javascript program, playlist.js, is used to present the updated



Recommended Playlist

- RelaxPlaylist (12 tracks)

1.Mono - Life In Mono

Your Playlist

Play Playlist Clear Playlist

- Add to playlist Click the blue icon

Figure 4.20: Recommended music playlist

playlist.

Artist

- Adaro (2 albums)
- Cara Dillon (1 album)
- Dana Winner (1 album)
- Norah Jones (2 albums)
- George Hamilton IV (1 album)
- Iridio (1 album)
- Kate St. John (1 album)
- Lene Marlin (1 album)
- Martin O'Donnell (1 album)
- Norah Jones (1 album)

Figure 4.21: Albums of artists

The user may also be further guided to the albums and the tracks, by following the links. The same request-response process updates the interface accordingly. Figure 4.22 shows the interface presenting the information about a selected album. The user can be further guided to the detailed music tracks if the user clicks on the album name. At any moment of the interaction, the user can easily exit the system by clicking on the hyperlink MainMenu to go back to the main menu as shown in Figure 4.18.

4.2 Experimental setup

An experimental on-board intranet that was used for experiments and user evaluation was designed and implemented. It consists of a high performance

Figure 4.22: Album information

server and six personal computers. All personal computers are connected to the server via an Ethernet hub. The user interacts with the heart rate controlled music recommendation system via a web browser from the personal computer. Figure 4.23 shows simulated on-board intranet.

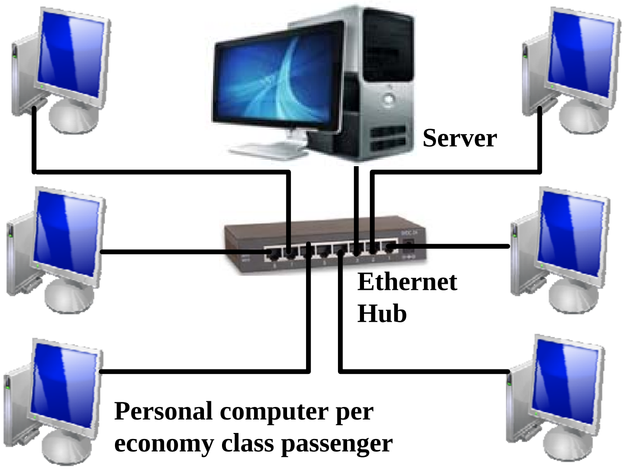


Figure 4.23: Simulated on-board intranet

The detailed configurations of the hardware are described in table 4.1. Six touch screen monitors are used to facilitate touch based interaction.

Device	Quantity	Configuration
Personal computer	6	Dell Inspiron 531
Touch screen monitor	6	LM104P-4RT industrial touch screen 10.4” monitor with power supply and controller for touch screen
Server	1	Dell PowerEdge 6800
Ethernet hub	1	HP ProCurve Switch 408

Table 4.1: Configuration of the simulated on-board intranet

4.3 System implementation within SEAT consortium

Within the SEAT project consortium, design and implementation of the heart rate controlled music recommendation system were a coordinated work between ETH Zurich, Starlab, and TUE. Zurich was responsible for the heart rate sensor selection or development. Starlab read the signals from the sensor. After processing, it stored the heart rate information to the database. In figure 4.24, components with the blue color were designed and implemented by ETH Zurich and Starlab.

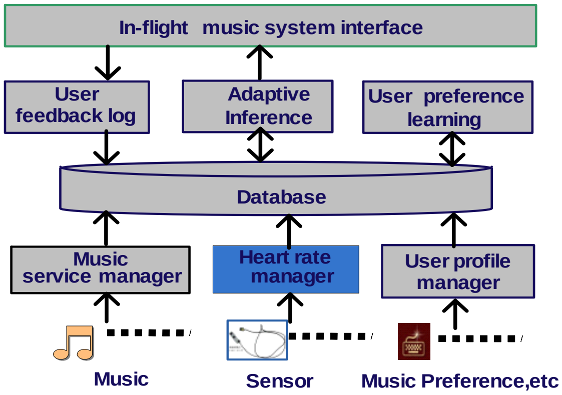


Figure 4.24: System integration schema within SEAT consortium

The heart rate sensor developed by ETH Zurich and the heart rate manager developed by Starlab have been successfully integrated with other components of the heart rate controlled music recommendation system. The integrated system functionalities have been tested according to the user scenario defined by the

SEAT consortium in chapter 3. The successful integration proves the success of the loosely coupled design among system components. The integrated system was demonstrated during the SEAT project final consortium meeting which was held in November, 2009.

4.4 Summary

This chapter presents the implementation detail of the software architecture that supports the framework design. The software architecture has five abstraction layers. The layers and the components in the layers are loosely coupled. This increases the flexibility of the software architecture.

The software architecture is implemented in a client/server structure using various tools and languages such as Java, Jamon, Max 5.1 and Javascript. The non-intrusive Emfit heart rate sensor is chosen for measuring the heart rate. An experimental setup that consists of several computers and touch screens is used for testing the software for user evaluation, which is the focus of the next chapter.

Chapter 5

Evaluation

To answer the hypotheses and research questions raised in chapter 1, a prototype of the heart rate controlled music recommendation system was designed and implemented in chapter 3 and 4. The system is an interactive system which is supposed to be used in the long haul flight environment. To the best of our knowledge, there is not a user model for the long haul environment which is sophisticated enough for us to test our system without field tests [4, 147]. So, laboratory experiments were set up to simulate long haul flights in which the prototype of the system was used by participants. The flight was simulated twice, first with the control group and then with the test group. The difference in the experiment setups between these two experiments was that the test group had the access to the recommended music playlists. The two groups were compared in terms of heart rate and stress. The differences between the two groups were analyzed statistically to validate the hypotheses and answer the research questions.

Next the setup, design, results, discussions and conclusions of the user experiments are presented.

5.1 User experiments

5.1.1 Setup

The user experiments were conducted in the cabin simulator built as a test bed for the SEAT project. It consists of a small scale aircraft cabin, a motion platform, a projection, and a control room. The aircraft cabin is divided into an economy class section, a business section, a lavatory and a kitchen. The cabin is supported by a motion platform that simulates the effects of taxing, taking off, landing and turbulence. The projector hung above the aircraft cabin projects the simulated window view on a wall next to the cabin. The control room is equipped with computers to support in-flight entertainment systems and with observation monitors that are connected to surveillance cameras installed in the cabin. A surround sound system is also installed to simulate the sound and noise during the flight. Figure 5.1 is the top view of the test bed. More details about the design of the test bed can be found in [192].

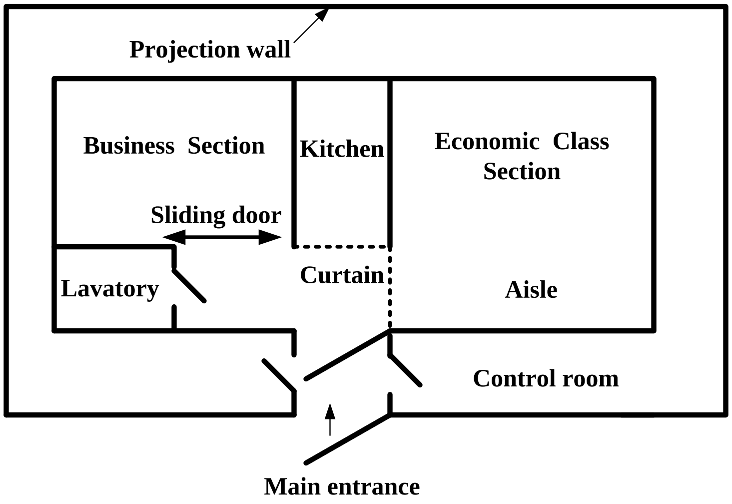


Figure 5.1: Top view of the test bed

The aircraft cabin in the flight simulator is equipped with a lavatory and kitchen to enable long-haul flight simulations. The lavatory is equipped with a camping toilet and a wash basin. The business class section is equipped with a massage chair, a touch screen monitor, a high quality surround sound system and a 47 inch Philips ambient light television. In this PhD project, it is used as the flight attendant rest place during the user experiments. Figure 5.2 shows the main entrance of the test bed, kitchen, lavatory and business class section.

There are six economy class seats in the economic class section. Each seat is equipped with a touch screen monitor which is connected to a personal computer in the control room via an EGA (Enhanced Graphics Adapter) extension cable. At each seat, a SONY NC40 noise canceling earphone is provided. An extension cable connects the earphone jack from the armrest of the seat to a personal computer in the control room. In each seat, an Emfit [51] sensor film is non-intrusively embedded under the cover of the seat. The Emfit processor and the power supply are installed under each seat. A USB extension cable helps to connect the processor to a personal computer in the control room. Under the hand luggage compartment, speakers are installed for the captain announcements. Figure 5.3 shows the economy class section.

The control room is equipped with computer systems which are used to support, control and monitor the cabin simulator. For supporting the in-flight entertainment system, six personal computers and a server computer are connected to form an on-board intranet providing in-flight entertainment to the "passengers". Each personal computer supports one in-seat touch screen and

(a) Main entrance (b) Kitchen

(c) Lavatory (d) Business section

Figure 5.2: Main entrance, kitchen, lavatory and business section

one normal LCD monitor in the control room via a video splitter. The detailed configuration is presented in the hardware section in chapter 4. For controlling and monitoring the cabin, an additional personal computer is used for observation and announcement, which is connected to the surveillance cameras and the announcement speakers inside the cabin. Two other computers are used, one for the window view projection, the other for controlling the motion platform (figure 5.4).

The window view is simulated with a 3m x 6m projection on a wall using a Sanyo PLC-WXU300 wide screen LCD projector. The wall is painted white and it is 1.3m away from the cabin windows (figure 5.5).

The motion platform is constructed using four compressed air bags controlled by a computer. Each air bag supports one of the four corners of the cabin. The computer controls the air bags to be inflated and deflated in order to move the cabin to simulate the situations of taking off, landing and turbulence. For details of the motion platform, the interested reader is referred to [192].

Figure 5.3: Economy class section

Figure 5.4: Control room

The test subjects are provided with in-flight entertainment during the simulated flights. The subjects are divided into two groups, control group and test group. The entertainment content they receive is the same but the test group would also receive the heart rate controlled music recommendations. Hence the graphic interface differs only in terms of these recommendations. Figure 5.6 is the main interface, Figure 5.7 is the interface for the movie part of the system, and Figure 5.8 is for the game part. They are the same for both groups.

However, the interface of the music part is different for these two groups. Figure 5.9 (a) shows the interface for the control group, and Figure 5.9 (b) shows the one for the test group. The only difference is that the test group has the access to the recommended music playlist.

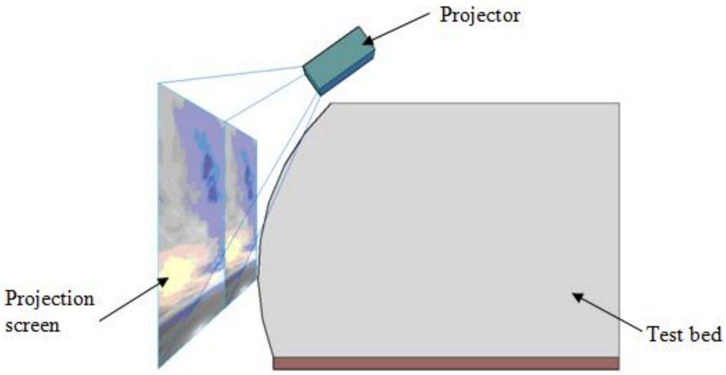


Figure 5.5: Projection

Figure 5.6: In-flight entertainment main interface

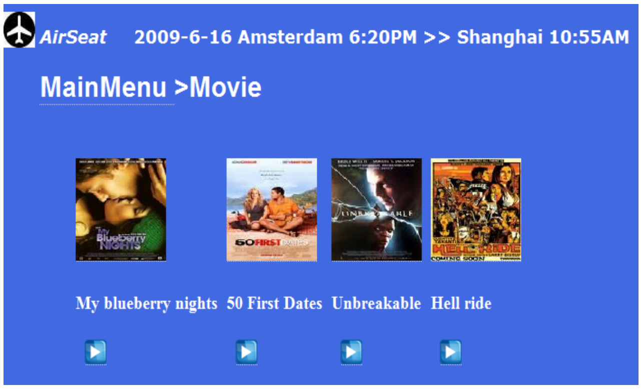
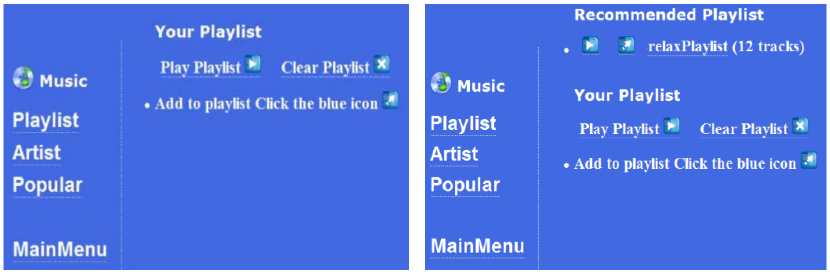


Figure 5.7: In-flight movie

Figure 5.8: In-flight game



(a) Music interface for the control group (b) Music interface for the treatment group

Figure 5.9: Music interface for the control and test groups

5.1.2 Hypotheses

We refine the hypothesis in chapter 1 into three hypotheses: (I) the passenger's heart rate deviates from the normal due to the unusual long haul flight cabin environment; (II) by properly designing a music recommendation system to recommend heart rate controlled personalized music playlists to the passenger, the passengers' heart rate can be uplifted, down-lifted back to normal or kept within normal; (III) the passenger's stress can be reduced by controlling his/her heart rate at normal. These three hypotheses are in line with the first three research questions in section 1.4 of chapter 1.

5.1.3 Participants

Test subjects. Twelve subjects were recruited by advertisements to participate in the experiments and were paid a fixed fee. Six were put in the control group and the rest in the test group. The experiment was conducted in a single-blind manner. The subjects did not know whether they were put in the control group or the test group. Each group had three males and three females. Half of the subjects in each group were from Asia and the others were from Europe. The ages of the subjects in the control group ranged from 21 to 33. The ages of the subjects in the test group ranged from 23-32. The professions in the control group included one newspaper reporter, two blue collar workers and three engineers. The professions in the test group included one student, two blue collar workers and three engineers. Table A.2 delineates the details of the subjects.

	Control group	test group
Number of subjects	6 (3 males, 3 females)	6 (3 males, 3 females)
Nationality	3 European, 3 Asian	3 European, 3 Asian
Age	21-33	23-32
Professions	Reporter: 1; Blue collar workers: 2; Engineers: 3	Student: 1; Blue collar workers: 2; Engineers: 3

Table 5.1: Test subjects' profile

Support staff. During the user experiments, a former flight attendant from Swiss Air provided professional cabin service, a "flight captain" and a technician provided technical support to simulate flights.

5.1.4 Procedure

The Koninklijke Luchtvaart Maatschappij (KLM) flight KL0895 from Amsterdam Schipol international airport to Shanghai Pudong international airport was simulated in the experiments. The simulation procedure not only addressed the importance of the cabin like physical set up, but also highlighted dynamic services such as flight attendant service and flight captain information service to create a virtual flight environment to subjects. The simulation procedure was a time driven unified workflow process which integrated the set up with dynamic simulation services. In the following, firstly, the dynamic simulation services are introduced. Secondly, the time-driven unified workflow simulation procedure is presented.

Dynamic services

(1) Flight attendant service

Flight attendant service includes: (a) cabin food and drink service; (b) safety instruction to ensure the safety and security inside the cabin during the experiment. Flight safety regulations are followed as well as administering unexpected events to ensure user experiments going smoothly.

(2) Flight captain information service

Captain information service includes safety instruction, flight attendant alert, turbulence alert, landing alert and captain information.

(3) Sky view simulation

To simulate sky view of KLM KL0895 flights, a local time and flying stage awareness sky view video from the cabin window point of view is needed. The flying stage-aware views included boarding, taxing, take off, flying, landing and un-boarding (figure 5.10). Its time-aware views include dawn, dusk, dark, day (figure 5.11). The local time was computed by the following equation where t_{depart} is the local time of the flight departure city, t_{flying} is the flight's relative flying time, Δt is the time difference between the destination city and the departure city. A simulation video was edited by the author of this thesis through dynamic composition of these views with local time and flying stage awareness.

$$T_{local} = t_{depart} + t_{flying} + \Delta t \tag{5.1}$$

Simulation procedure

The simulation procedure was a time-driven workflow (figure 5.12). It coordinated the static set up with the dynamic services to create a virtual environment to give subjects long haul flight experiences. In the simulation procedure, the boarding, taxing, take off, flying, turbulence, landing, un-boarding flying situations are simulated by the synchronization of moving platform service, sky view projection service, and are enhanced by the captain information service and flight attendant service.

KLM KL0895 flights were simulated in the set up. The flight left Amsterdam at 6:20PM and arrived in Shanghai next day at 4:55AM (Shanghai local time 10:45 AM). The control group user experiment was conducted from the night of 31st July to the morning of 1st August in 2009. The test group user experiment was conducted from the night of 7th August to the morning of 8th August in 2009.

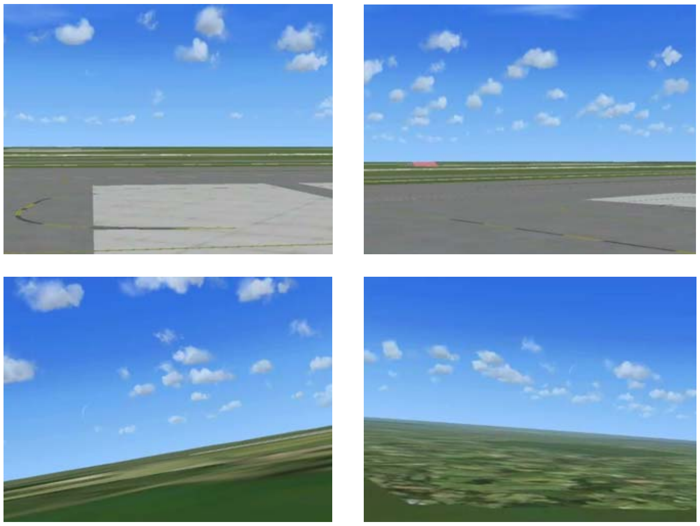


Figure 5.10: Boarding, taxing, take off and landing views

Figure 5.11: Dawn, dusk, night and day views

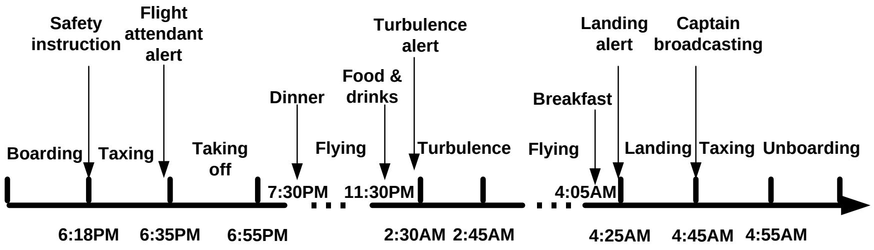


Figure 5.12: Simulation Procedure

Figure 5.13: User experiment picture taken from the observation camera

5.1.5 Experimental Variables

Variables

Experimental variables include simulation, controlled, independent and dependent variables. The simulation variable measures subjects' long haul flight experience. In this PhD project, the experience is measured by a presence questionnaire. Presence is defined as the subjective experience of being in one place or environment, even when one is physically situated in another [16, 74, 209]. In this thesis, presence means the "passenger's" subjective experience of being in the long haul flight; even when the "passenger" is physically sitting in the test bed. The presence questionnaire in [209] was customized by me and Cheefai Tan to measure the test subjects' presence. The customized presence questionnaire can be found in appendix C. Controlled variables include the cabin environment (temperature, noise and humidity) and hearing ability. Hearing ability of the subjects is important for the effect of music listening. It is measured by the hearing ability questionnaire (appendix D). Independent variables include the test condition. The test condition values are the control group and the test group. Dependent variables include the passenger's heart rate and stress.

Simulation variables	Controlled variables	Independent variables	Dependent variables
Presence	Temperature Humidity Noise Hearing ability	Test condition (control group, test group)	Heart rate Stress

Table 5.2: Variables

Data Acquisition

Simulation variable. The presence is measured by the questionnaire in appendix C. It consists of five questions each on a 1 to 7 scale where 1 represents 'not at all', 'at no time', etc. and 7 represents 'very much', 'almost all the time', etc. The questionaires were filled out by the subjects right after the user experiments.

Control variables. The cabin environment was measured every hour during user experiments (started from 6:30PM to 4:30 AM). The cabin temperature (Celsius scale) and humidity (percentage of water in the air) were measured by the wireless air temperature/humidity monitor and recorded by the simulated flight captain in the control room. The cabin noise was measured by the flight attendant with a hand-held noise measurement equipment in decibel (dB). Hearing ability was measured by questionnaire in appendix D. It is composed by four questions to investigate the subjects' hearing abilities. Test subjects need to fill out the questionnaires before the user experiments.

Independent variable. Test condition values are the control group and the test group.

Dependent variables. Heart rate was measured online by the EMFIT bio sensor. It was recorded to MySQL database with BPM values at a rate of one Hz. The stress was measured by two methods. One was the subjective self report stress scale questionnaire [15] (refer to appendix B). It was distributed by the flight attendant to subjects every hour (started from 7:00 PM until next day 5:00 AM). For each subject, he/she needs to report his/her stress scale 11 times with stress scale questionnaires [15]. If the test subject was sleeping, his/her stress scale was reported by the flight attendant. Its value was two which is the middle scale point between the "deep, dreamless sleep" state and "I am on the green in a forest and dreaming with open eyes" state. The flight attendant collected questionnaires five minutes after the distribution. The stress scale was measured by the distance between the "deep, dreamless sleep" state and the self report state in centimeters.

The other was the objective stress level indicated by the ratio between LF power and HF power of the heart rate variability. LF band power (0.04-0.15 Hz) and the HF band power (0.15-0.4 Hz) were computed based on five minutes of heart rate every hour (started from 7:00 PM-7:05PM until next day 5:00-5:05AM) with Fast Fourier transformation (Welch's periodogram where the window is 52s with 50% overlap).

5.1.6 Results

In this subsection, the results of the flight simulation are reported. Results of dependent and independent variables are reported according to our three hypotheses.

Flight simulation

For the first presence feeling question "I had a sense of being in a long haul flight" in the presence questionaire (see appendix C), The mean is 4.00 (SD=0.74, N=12); for the second presence feeling question "There were times during the experience when the virtual 'long haul flight' became more real for me compared to the 'real flight"', the mean is 3.75 (SD=1.22,; N=12) for the third presence feeling question "the test bed seems to me to be more like somewhere that I visited", the mean is 3.50 (SD=0.79, N=12); for the fourth presence feeling question "I had a stronger sense of being in the virtual reality of the flight", the mean is 3.92 (SD=0.79,N=12); for the fifth presence feeling question "I had a stronger sense of being in the virtual reality of the flight", the mean is 3.50 (SD=1.08, N=12). Table 5.3 reports the result of the test subjects' presence feelings.

In order to compare flight simulation effects between the control group and test group, a one-way ANOVA test was performed. For the "I had a sense of being in a long haul flight" presence feeling, there is no significant difference between the two groups (F(1,10)=0.00, p=1.0); for the "There were times during the experience when the virtual 'long haul flight' became more real for me compared to the 'real flight"' presence feeling, there is no significant difference between the two groups (F(1,10)=0.05, p=0.83); for the "The test bed seems

Questions	Range	Control group M (SD,N)	Test group M (SD,N)	Total M (SD,N)
Being there	[1...7]	4.00 (0.89,6)	4.00 (0.63,6)	4.00 (0.74,12)
Real flight	[1...7]	3.83 (1.47,6)	3.67 (1.03,6)	3.75 (1.22,12)
Lab or somewhere	[1...7]	3.67 (0.82,6)	3.50 (0.84,6)	3.58 (0.79,12)
Lab or flight	[1...7]	4.00 (0.89,6)	3.83 (0.75,6)	3.92 (0.79,12)
Sit in lab Or flight	[1...7]	3.33 (1.21,6)	3.67 (1.03,6)	3.50 (1.08,12)

Table 5.3: Result of the presence feeling questions

to me to be more like somewhere that I visited" presence feeling, there is no significant difference between the two groups (F(1,10)=0.12, p=0.73); for the "I had a stronger sense of being in the virtual reality of the flight" presence feeling, there is no significant difference between the two groups (F(1,10)=0.12, p=0.72); for the "During the experience I often thought that I was really sitting in the test bed" presence feeling, there is no significant difference between the two groups (F(1,10)=0.26, p=0.62). These results suggest that the test subjects of the control group and the test group share the same "flight experience". Table 5.4 presents the ANOVA report for presence feelings between the control group and the test group.

Experiment control

During user experiments, in order to control effects of spurious, intervening, and antecedent variables, measures were taken to try to keep temperature, humidity and noise between the control group and test group the same. Measures included using air condition and electric fan to control cabin temperature, the simulation procedure was strictly followed.

The temperature, humidity and noise inside the cabin were recorded each hour from 6:30pm until 4:30am. For each of them, there were 22 data collected. (control group: 11 data, test group: 11 data). The temperature mean in the control group is 29.35°C and the standard deviation is 1.76°C, its mean in the test group is 29.45°C and the standard deviation is 0.82°C; the humidity mean in the control group is 43% and the standard deviation is 5%, its mean in the test group is 42% and the the standard deviation is 5%; the noise mean in the control group is 70.18dB and the standard deviation is 0.6dB, its mean in the test group is 70.9dB and the standard deviation is 1.04dB. Table 5.5 reports the mean, stand deviation and number of temperature, humidity and noise during user experiments. The temperature, humidity, noise values through the user experiments are illustrated in figure 5.14, 5.15 and 5.16.

		Sum of Squares	df	Mean Squares	F	Sig.
Being there	Between Groups	0.00	1	0.00	0.00	1.00
	Within Groups	6.00	10	0.60		
	Total	6.00	11			
Real flight	Between Groups	0.08	1	0.08	0.05	0.83
	Within Groups	16.17	10	1.62		
	Total	16.25	11			
Lab or somewhere	Between Groups	0.08	1	0.01	0.12	0.73
	Within Groups	6.83	10	0.68		
	Total	6.92	11			
Lab or flight	Between Groups	0.08	1	0.01	0.12	0.73
	Within Groups	6.83	10	0.68		
	Total	6.92	11			
Sit in lab Or flight	Between Groups	0.33	1	0.33	0.26	0.62
	Within Groups	12.67	10	1.27		
	Total	13.00	11			

Table 5.4: ANOVA report for presence feelings between the control group and the test group

	Control group	test group
Controlled variable	M (SD,N)	M (SD,N)
Temperature (°C)	29.35 (1.76,11)	29.45 (0.82 11)
Humidity (%)	43% (5%,11)	42% (5%,11)
Noise (dB)	70.18 (0.6,11)	70.9 (1.04,11)

Table 5.5: Mean,standard deviation and number of temperature, humidity and noise

In order to compare the differences of the temperature, humidity and noise between the control group and test group, an independent samples T test was performed. For the temperature, the variances of the control group and test group are significantly different (p=0.007), however, there is not a significant temperature difference between the control group and test group (t=-0.155, df=20, p=0.879); for the humidity, the variances between the control group and test group are not significantly different (p=0.888), there is not a significant humidity difference between the control group and test group (t=0.42, df=20, p=0.967); for the noise, the variances between the control group and test group

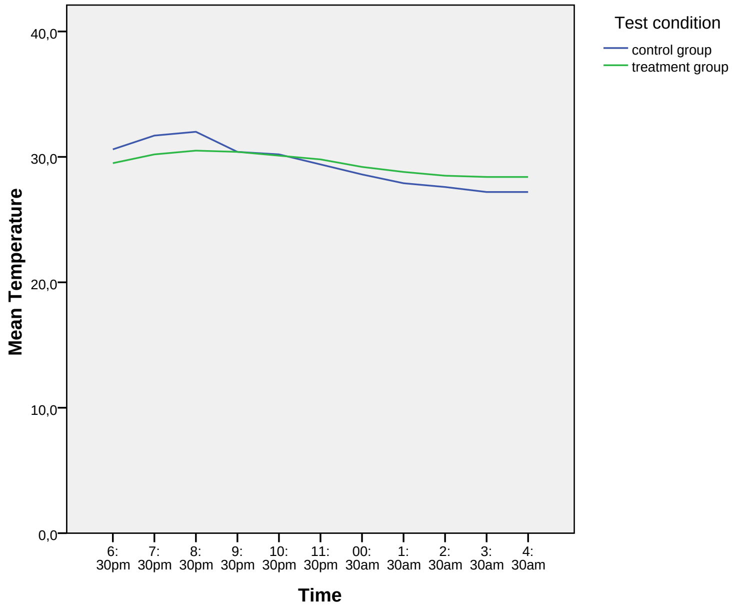


Figure 5.14: The temperature of the control group and test group

are significantly different (p=0.001), however, there is not a significant noise difference between the control group and test group (t=-2.000, df=20, p=0.063). These results suggest that temperature, humidity and noise were approximately equal between the control group and the test group during user experiments. The result of the T test is reported in table 5.6.

For the controlled variable hearing ability, according to answers to four questions in the hearing ability questionnaires (see appendix D), no tested subjects had hearing problems.

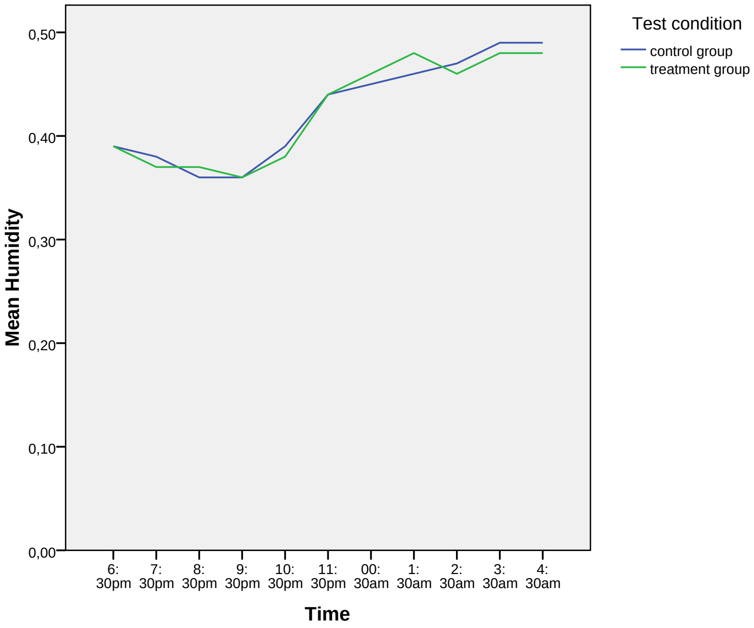


Figure 5.15: The humidity of the control group and test group

		Levene's Test for Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (2-tailed)
Temperature	Equal variances assumed	9.132	0.007	-0.155	20	0.878
	Equal variances not assumed			-0.155	14.144	0.879
Humidity	Equal variances assumed	0.002	0.888	0.42	20	0.967
	Equal variances not assumed			0.42	20.000	0.967
Noise	Equal variances assumed	19.048	0.000	-2.000	20	0.059
	Equal variances not assumed			-2.000	16.000	0.063

Table 5.6: Independent samples T test for the temperature, humidity and noise between the control group and the test group

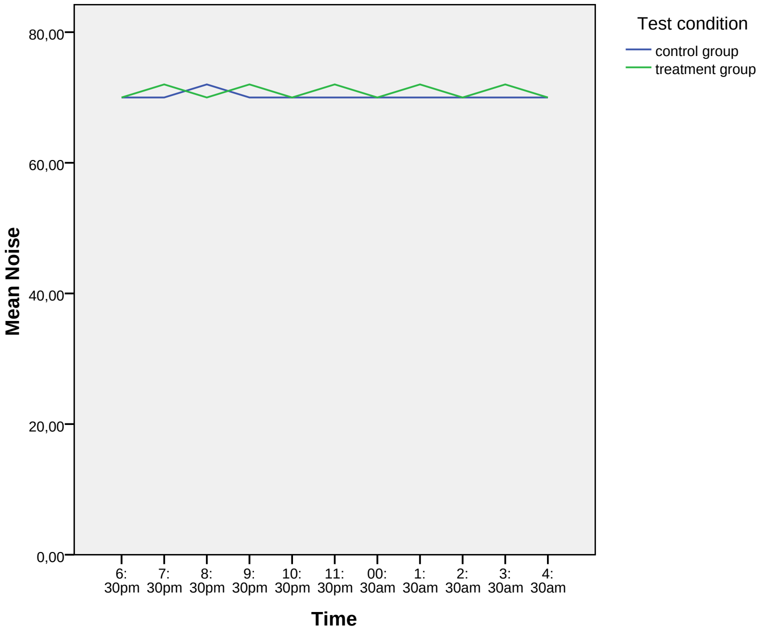


Figure 5.16: The noise of the control group and test group

Hypothesis I

Hypothesis I is that passenger's heart rate deviates from the normal during long haul air travels. During the control group user experiment, there were 215998 heart rate data collected. The maximum of the heart rate is 149 and the minimum is 41. The mean of the heart rate is 66 and the standard deviation is 11. The median of the heart rate is 65 and the mode is 64. The skewness is 2. Figure 5.17 illustrates the heart rate of the test subjects in the control group. The test subjects' heart rate was in the bradycardia state 24.6% of time. The test subjects' heart rate was in the tachycardia state 7.3% of time. The subjects' heart rate was in the normal state 68.1% of time. These results validated hypothesis i.

Hypothesis II

During the test group user experiment, four test subjects listened to ten recommended uplifting music playlists. The mean listening time of the uplifting music playlists was 22 minutes. The mean of the bradycardia state duration was 6.86 seconds and the standard deviation was 9.02 seconds. The number of the bradycardia state duration was 481. Six subjects listened to 20 recommended keeping music playlists. The mean listening time of the keeping music playlists was 25 minutes. The mean of the normal state duration was 29.79 seconds and

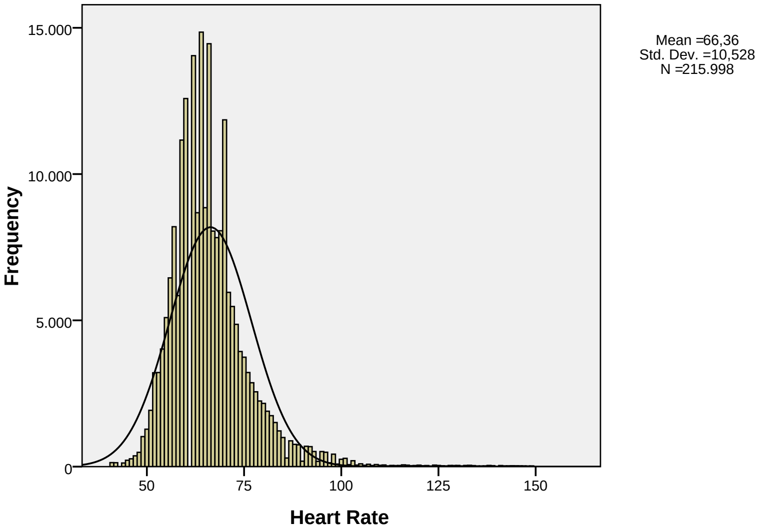


Figure 5.17: Histogram of heart rate for all test subjects in the control group

the standard deviation was 53.32 seconds. The number of the normal state duration was 628. Three subjects listened to three recommended down-lifting music playlists. The playing time of the down-lifting music playlists was 313, 223 and 1377 seconds. The mean of the tachycardia state duration was 6.53 seconds, the standard deviation was 6.88 seconds and the number of the tachycardia state duration was 49. There were two subjects in the control group listening to music. One listened to music for 35 minutes. Another listened to music for 28 minutes. There were six subjects sitting in the seat and doing nothing. The time durations were 167, 98, 131, 122, 199, and 120 minutes. The mean of the bradycardia state duration for test subjects listening to music and sitting in the seat and doing nothing was 14.78 seconds and the standard deviation was 17.50 seconds. The number of the bradycardia state duration was 957. The mean of the normal state duration for test subjects listening to music and sitting in the seat and doing nothing was 24.66 seconds and the standard deviation was 40.82 seconds. The number of the normal state duration was 1262. The mean of the tachycardia state duration for test subjects listening to music and sitting in the seat and doing nothing was 13.89 seconds and the standard deviation was 11.87 seconds. The number of the tachycardia state duration was 186. Table 5.8 reports the results.

Hypothesis II is that the long haul flight passenger's heart rate can be uplifted, down-lifted if it deviates from normal and can be kept within normal by the heart rate controlled music recommendation system. An MANOVA examined test condition and heart rate state as fixed factors and the heart rate state duration as the dependent variable. A univariate analysis was then con-

Test condition	Heart rate state	M (SD,N)
Control group	bradycardia	14.78 (17.50,957)
	normal	24.66 (40.82,1262)
	tachycardia	13.89 (11.87,186)
	total	19.89 (32.12,2405)
Test group	bradycardia	6.86 (9.02,481)
	normal	29.79 (53.32,628)
	tachycardia	6.53 (6.88,49)
	total	19.28 (41.32,1158)
Total	bradycardia	12.13 (15.65,1438)
	normal	26.36 (45.41,1890)
	tachycardia	12.35 (11.40,235)
	total	19.70 (35.37,3563)

Table 5.7: Duration in seconds of bradycardia, normal and tachycardia states

ducted to check on the uplifting, keeping and downlifting effects. The mean difference of bradycardia, normal and tachycardia state duration between the control group and test group is significant (F(2,16327.242)=13.686, p=0.001). The result suggests that the uplifting music reduces the bradycardia state duration from 14.78 seconds in the control group to 6.86 seconds in the test group. The keeping music increases the normal state duration from 24.66 seconds in the control group to 29.79 seconds in the test group. The down-lifting music reduces the tachycardia state duration from 13.89 seconds in the control group to 6.53 seconds in the test group. The system achieved its main design objective. Table 5.8 reports the differences of the bradycardia, normal and tachycardia state duration in seconds between the control group and test group. Figure 5.18 illustrates the mean differences of the bradycardia, normal and tachycardia state duration in seconds between the control group and the test group.

Because there is a formal relation between the bradycardia and tachycardia state duration with the normal state duration, a reduction of the durations in the bradycardia and tachycardia state means automatically an increase of the normal state duration, we exclude the normal state durations and repeat the univariate analysis. The mean difference of bradycardia and tachycardia state duration between the control group and test group is still significant (F(1,8070.426)=37.388, p=0.001). Table 5.9 reports the differences of the bradycardia and tachycardia state duration in seconds between the control group and test group.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	212115.551[a]	5	42423.110	35.559	.000
Intercept	297659.230	1	297659.230	249.50	.000
TestCondition	3285.021	1	3285.021	2.754	.097
State	209789.937	2	104894.968	87.92	.000
TestCondition*State	32654.483	2	16327.242	13.686	.000
Error	4243566.263	3557	1193.018		
Total	5837891.000	3563			
Corrected Total	4455681.814	3562			

a. R Squared = .048 (Adjusted R Squared =.046)

Table 5.8: Differences of the bradycardia, normal and tachycardia state duration in seconds between the control group and test group

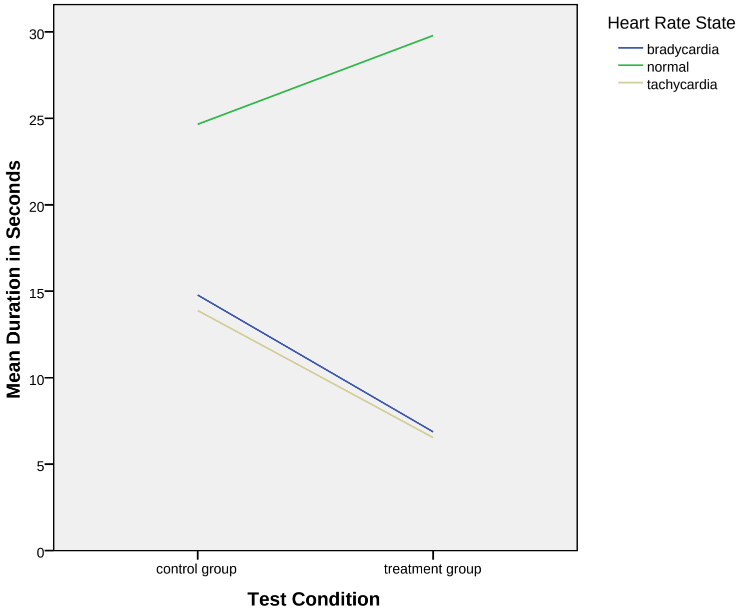


Figure 5.18: Mean difference of bradycardia, normal and tachycardia duration in seconds between the control group and test group

Hypothesis III

Stress scale

For the control group and the test group, during user experiments, each of them had 66 stress scale data collected. Table 5.10 reports the mean, standard deviation and number of the stress scale from 7pm until 5am.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	22176.626^a	3	7392.209	34.264	.000
Intercept	61209.921	1	61209.921	283.570	.000
TestCondition	8070.426	1	8070.426	37.388	.000
State	52.381	1	52.381	.242	.632
TestCondition*State	10.899	1	10.899	.050	.822
Error	360261.841	1669	215.855		
Total	630020.000	1673			
Corrected Total	382438.467	1672			

a. R Squared = .058 (Adjusted R Squared =.056)

Table 5.9: Differences of the bradycardia and tachycardia state duration in seconds between the control group and test group excluding data for normal state duration in seconds

	Test condition		
	Control group	test group	Total
Time	M (SD, N)	M (SD, N)	M (SD, N)
7pm	11.72 (1.53,6)	9.08 (4.27,6)	10.40 (3.35,12)
8pm	10.88 (2.55,6)	10.17 (2.79,6)	10.53 (2.57,12)
9pm	9.88 (2.65,6)	7.40 (4.43,6)	8.64 (3.71,12)
10pm	9.85 (2.69,6)	8.35 (2.87,6)	9.10 (2.77,12)
11pm	11.50 (1.66,6)	7.67 (4.73,6)	9.58 (3.93,12)
12pm	9.82 (2.62,6)	4.08 (4.2,6)	6.95 (4.48,12)
1am	7.88 (3.34,6)	5.90 (4.26,6)	6.89 (3.79,12)
2am	6.97 (5.04,6)	3.68 (4.58,6)	5.33 (4.90,12)
3am	5.10 (2.41,6)	2.08 (1.11,6)	3.59 (2.38,12)
4am	7.63 (2.93,6)	2.67 (1.03,6)	5.15 (3.33,12)
5am	8.25 (3.38,6)	8.22 (3.66,6)	8.23 (3.36,12)

Table 5.10: Stress scale of the control group and test group

In order to examine whether there is a significant difference of the stress scale between the control group and test group, a MANOVA examined the stress scale as within-subjects variables and test condition as the inter-subject correlation factor. Repeated measures analysis was then conducted. The analysis result indicates that the stress scale difference between the control group and the test group is significant (F(1,7769.404)=264.899, p=0.016). It suggests that the recommended music reduced the test subjects' stress scale. Table 5.11 reports the analysis result of the stress scale differences between the control group and test group. Figure 5.19 illustrates the stress scale of the control group and the test group from 7pm until 5am.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	7769.404	1	7769.404	264.899	.000
TestCondition	248.464	1	248.464	8.471	.016
Error	293.297	10	29.330		

Table 5.11: Analysis result of the stress scale differences between the control group and test group

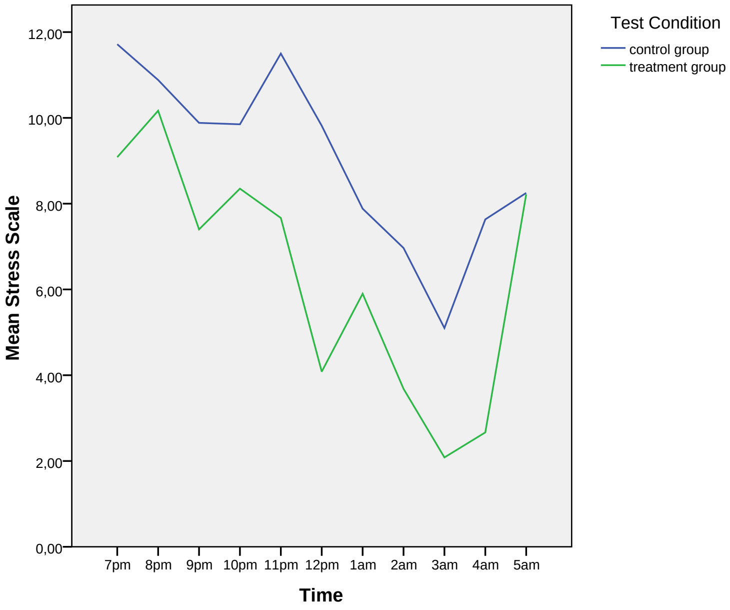


Figure 5.19: Stress scale of the control group and the test group

Stress level

For the control group and the test group, each of them had 66 stress level data computed by the ratio of LF and HF. Table 5.12 reports the mean, standard deviation and number of stress level from 7pm until 5am.

In order to examine whether there is a significant difference of the stress level between the control group and test group, a MANOVA examined the stress level as within-subjects variables and test condition as the between-subject factor. Repeated measures analysis was then conducted. The analysis result indicates that the stress level mean difference between the control group and test group is not significant F(1,14.733)=2.988, p=.115). Table 5.13 reports the analysis result of the stress level differences between the control group and the test group. Figure 5.20 illustrates the stress level of the control group and the test group from 7pm until 5am.

	Test condition		
	Control group	test group	Total
Time	M (SD, N)	M (SD, N)	M (SD, N)
7pm	2.40 (2.88,6)	2.07 (1.57,6)	2.23 (2.22,12)
8pm	2.88 (1.91,6)	2.40 (1.53,6)	2.64 (1.67,12)
9pm	3.45 (1.71,6)	2.75 (2.12,6)	3.10 (1.87,12)
10pm	2.25 (1.81,6)	1.97 (0.94,6)	2.11 (1.39,12)
11pm	2.20 (1.46,6)	1.08 (0.78,6)	1.64 (1.26,12)
12pm	3.27 (2.23,6)	1.83 (1.21,6)	2.55 (1.87,12)
1am	3.00 (1.31,6)	1.60 (1.07,6)	2.30 (1.35,12)
2am	2.65 (2.15,6)	2.67 (1.13,6)	2.66 (1.64,12)
3am	3.90 (3.13,6)	1.55 (1.19,6)	2.73 (2.57,12)
4am	2.10 (1.31,6)	3.00 (1.69,6)	2.55 (1.52,12)
5am	2.62 (1.49,6)	2.45 (1.44,6)	2.53 (1.40,12)

Table 5.12: Mean, standard deviation and number of the stress level

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	797.729	1	797.729	161.805	.000
TestCondition	14.733	1	14.733	2.988	.115
Error	49.302	10	4.930		

Table 5.13: Analysis result of the stress level differences between the control group and test group

As reported in table 5.13 and illustrated in figure 5.20, the results showed that except for 2AM and 4AM the mean LF/HF of the test group is lower than that of the control group. According to flight attendant reports and analysis of the video recordings, at 2AM, there were four subjects sleeping from the test group, while only two persons sleeping from the control group.

Before analyzing the stress level of sleeping persons, some knowledge of sleep needs to be acquired. Sleep is prompted by natural cycles of activity in the brain and consists of two basic states: rapid eye movement (REM) sleep and non-rapid eye movement (NREM) sleep. There are four stages in NREM sleep. During sleep, the body cycles between non-REM sleep and REM sleep. One cycle lasts usually 90 to 100 minutes. Non-REM dreams are more likely to consist of brief, fragmentary impressions that are less emotional and less likely to involve visual images than REM sleep dreams. About 20 percent of sleep is REM sleep. Dreams generally occur in the REM stage of sleep. According to [48], compared to wake and NREM sleep, REM sleep is associated with decreased HF power, and significantly increased LF power to HF power ratio, which means high stress level.

It is not clear which state (Non-REM and REM) of sleeping test subjects was in at 2:00AM. In the control group, one sleeping test subject stress level was

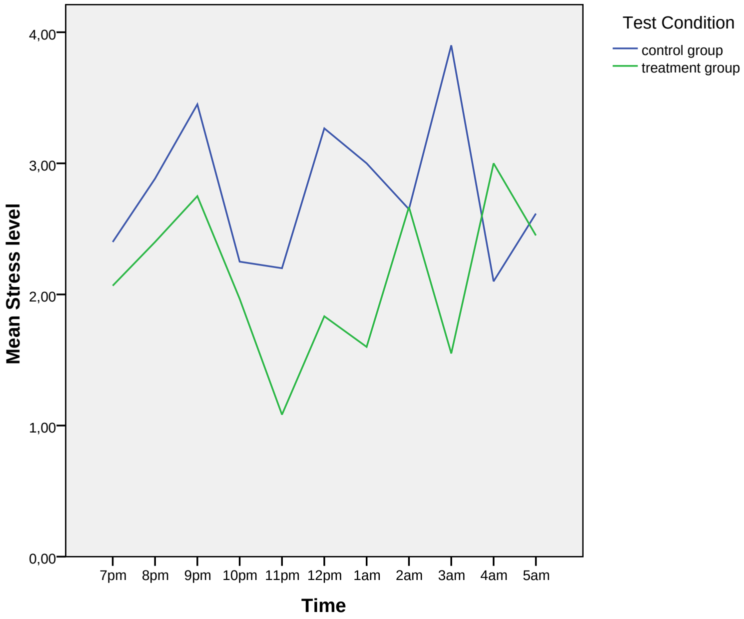


Figure 5.20: Stress level of the control group and the test group

6.4 and the other was 3.5. In the test group, the stress level data for sleeping test subjects were 3.7, 3.8, 3.2, and 2.7. For sleeping test subjects, the mean stress level of the test group is lower than that of the control group. According to [48], maybe, the sleep person with 6.4 stress level value was in a REM state of sleep, the others were in NREM states of sleep. At 4PM, there were four test subjects sleeping in the test group. There were no test subjects sleeping in the control group. One sleeping test subject's stress level is 6.0 which are much higher than others.

We exclude all data for 2AM and 4AM and conduct the MANOVA "repeated measures" analysis again. The stress level difference between the control group and test group becomes significant F(1,2.531)=5.335, p=.044). The result suggests that the recommended music reduced the test subjects' stress level. Table 5.14 reports the analysis result of the stress level differences between the control group and test group. Figure 5.21 illustrates the stress level of the control group and the test group from 7pm until 5am (excluding 2AM and 4AM).

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	70.621	1	70.621	148.861	.000
TestCondition	2.531	1	2.531	5.335	.044
Error	4.744	10	0.474		

Table 5.14: Analysis result of the stress level differences between the control group and test group excluding data for sleeping hours at 2AM and 4AM

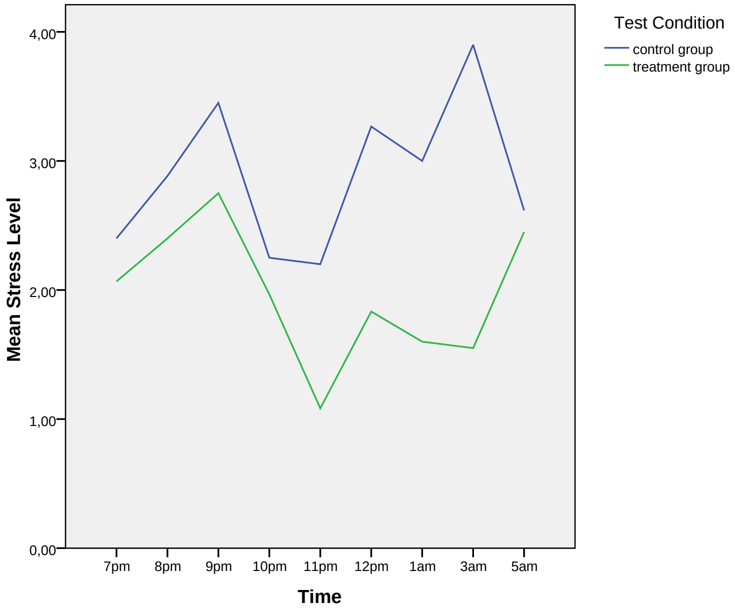


Figure 5.21: Stress level of the control group and test group excluding data for sleeping hours at 2AM and 4AM

5.1.7 Discussions and conclusions

The user experiment validates hypothesis I that the long haul flight passenger's heart rate deviates from normal. During the control group user experiment, all the test subjects had bradycardia, normal and tachycardia states. In our user experiment, the test subjects' heart rate was in the bradycardia state 24.6% of time and in the tachycardia state 7.3% of time.

The user experiment validates hypothesis II that the user's heart rate can be uplifted, down-lifted or kept at normal level by the implemented heart rate controlled music recommendation system in the simulated long haul flight environment. The statistical analysis was used to test for the bradycardia, normal and tachycardia durations between the periods of listening to the recommended music in the test group, and the periods of listening to music and the periods of sitting in the seat and doing nothing in the control group. Results showed that their mean duration differed significantly. The uplifting music reduces the bradycardia state duration from 14.78 seconds in the control group to 6.86 seconds in the test group. The keeping music increase the normal state duration from 24.66 seconds in the control group to 29.79 seconds in the test group. The down-lifting music reduces the tachycardia state duration from 13.89 seconds in the control group to 6.53 seconds in the test group. These results indicate that the system had achieved its main design objective.

The user experiment validates hypothesis III that by listening to the heart rate controlled personalized music playlists, the passengers' stress can be reduced too. The stress was measured by both subjective and objective methods. The subjective measurements were done by the test subjects reporting their stress scale using the stress scale questionnaire [15] every hour from 7pm until 5am next day. The objective measurements were done by calculating the ratio between the LF power and HF power of the heart rate variability. The statistical analysis was used to test stress difference between the control group and the test group. Results showed that for both subjective and objective measurements, stress differed significantly between the control group and test group. For the subjective measurement, the mean stress scale of the test group was lower than the control group significantly. For the objective measurement, except 2am and 4am, the mean stress level of the test group was lower than that of the control group. However, according to [48], REM sleep is associated with significantly increased LF power to HF power ratio. If we skip the stress level at 2am and 4am, the mean LH/HF of the test group is lower than that of the control group and their difference is significant.

It is interesting to find that the stress scale and the stress level have been reduced significantly by controlling only the passenger's heart rate at normal with music. I suggest the reason may be as follows. The autonomic nervous system regulates key functions of the body including the activity of the heart. It is composed by two subsystems: the parasympathetic nervous system and the sympathetic nervous system. The sympathetic nervous system is the fight-or-flight branch of autonomic nervous system. The activation of the sympathetic nervous system causes the increase of the sympathetic branch activity that accelerates the heart rate [57]. The parasympathetic branch induces the relaxation response that slows down the heart rate [57]. There is a balance between the parasympathetic nervous system and the sympathetic nervous system under normal situations, placing the body in a state of homeostasis. However, under a state of mental stress, this balance will be altered [146]. In our design, we reverse the effects of the sympathetic nervous system on heart rate under stress situations and help parasympathetic nervous system to slow down heart rate. However, the relation between the music tempo and the heart rate variability is not known yet.

5.2 Summary

Two user experiment were designed and conducted to validate the hypothesis and answer the set research questions. The experiments simulated a scheduled KLM long haul flight from Amsterdam to Shanghai. One user experiment was for the control group; the other user experiment was for the test group. The control group was provided with an in-flight entertainment which included on demand entertainment systems which served movies, games and music to the passengers, without the heart rate controlled recommendations. The test group was provided with the same content in the same simulated environment, as well as the heart rate controlled music recommendations. User experiment results validated the hypothesis and answered the research questions. Also, the designed framework and system were sufficiently effective and robust to undergo the extensive use (twice, each for 10 hours and 35 minutes by 6 participants simultaneously) during these experiments, which to some extent validated the design and answered the research question four in section 1.4 of chapter 1. The heart rate controlled in-flight music recommendation system achieved its design objectives.

Chapter 6

Conclusions

The focus of this thesis is on how to design a system that embeds biosignals into the personalized entertainment recommendation process to reduce stress. As a starting point, this project aims to contribute to the field of entertainment recommendation systems at two levels. The first is the mechanism of embedding the biosignal non-intrusively into the recommendation process. The second is the strategy of the biosignal controlled recommendation to reduce stress. Heart rate controlled in-flight music recommendation is chosen as its application domain.

The hypothesis is that, the passenger's heart rate deviates from the normal due to unusual long haul flight cabin environment. By properly designing a music recommendation system to recommend heart rate controlled personalized music playlists to the passenger, the passengers' heart rate can be uplifted, down-lifted back to normal or kept within normal, their stress can be reduced. Four research questions have been formulated based on this hypothesis.

To answer these research questions, research and user experiments have been carried out by designing and implementing the heart rate controlled music recommendation system for long haul flight economy class passengers in the context of the SEAT project. An adaptive framework was designed and implemented, which integrates the concepts of control systems, context adaptive systems, user profiling, and using music to adjust the user's heart rate. The framework was then implemented with a component-based architecture with five abstraction levels.

Two experiments were conducted to simulate the long haul flights that took the same schedule as the KLM flights from Amsterdam to Shanghai. One was for the control group; the other was for the test group. The difference in the setups between these two experiments was that the test group had access to the recommended music playlists.

The experiments results validated the hypothesis and answered the research questions. The passenger's heart rate deviates from normal. In our user experiments, the passenger's heart rate was in the bradycardia state 24.6% of time and was in the tachycardia state 7.3% of time. The recommended uplifting music reduces the average bradycardia state duration from 14.78 seconds in the control group to 6.86 seconds in the test group. The recommended keeping music increases the average normal state duration from 24.66 seconds in the control group to 29.79 seconds in the test group. The recommended down-lifting music reduces the average tachycardia state duration from 13.89 seconds in the control group to 6.53 seconds in the test group. Both the stress scale and the stress level values have been reduced significantly.

In addition to being used extensively in the user experiments, the system had also been integrated with other SEAT project systems.

Next in this concluding chapter, major contributions and findings of this PhD project are presented first. Then, limitation and future research directions are discussed.

6.1 Major contributions and findings

Current entertainment recommender systems mainly consider properties of the content, user profile and the context for recommendation. Little attention has been paid to biosignals of the user and the bio effects of these recommended entertainment contents on the user. This PhD project contributes to this field with: (1) mechanisms to incorporate the biosignal non-intrusively into the recommendation process; (2) biosignal controlled entertainment recommendation strategies to reduce user's stress. The resulting mechanisms and strategies complement the current entertainment recommendation methods. In the following, the mechanisms and strategies are elaborated from three abstraction levels: model, design and implementation. Following the summary of the contributions, the findings during the evaluation of the system are reported.

6.1.1 Contributions

Model

The goal of this project was to develop a next generation entertainment recommendation system that increases the user's comfort level by reducing the stress of the user. The design challenges of such a system include: how to model the user's stress with biosignals; how to relate the entertainment to stress; and how to reduce the user's stress by the entertainment recommendations. This PhD project answered these design challenges with: heart rate was selected as the indicator of stress; the relation between the heart rate and music tempos was identified; the algorithm of controlling the user's heart rate at normal was designed. Long haul flights were chosen as the system's application environment.

A hypothesis in the field of biosignal controlled entertainment systems was made and validated. The hypothesis is that, for the long haul flights, by properly designing a music recommendation system that adapts the recommendation list to the passenger's heart rate and that keeps the passenger's heart rate within the normal range, stress can be reduced.

Design

This PhD project contributes to the biosignal controlled entertainment systems with a workable framework. Based on the context and content filtering recommendation methods, it integrates several concepts into a discrete event based feedback system, including context adaptive systems, user profiling, and the methods of using music to adjust the heart rate. The feedback control loop includes the sensors for measuring the passenger's heart rate, the modules for acquiring and modeling the heart rate signal, and an adaptive control unit that integrates the music adaptation strategies and the system-user interaction components. They are coordinated to regulate the passenger's heart rate at normal thus reduce stress with heart rate aware and personalized music recommendations. The framework was validated during user experiments to be a workable solution for this type of application.

Implementation

Two principles are identified to implement biosignal controlled entertainment recommendation systems: (1) Non-intrusiveness. In the implementation of the framework, the heart rate is measured non-intrusively in the music recommendation process. This is done from both hardware and software points of view. For the hardware part, EMFIT sensors are used to measure the passenger's heart rate. These sensors do not need direct body contact to measure a user's heart rate. It is embedded under the cover of the passenger's seat to measure the passenger's heart rate through calculating the body micro-movement caused by the heart activation. The software part introduces five abstraction layers, to hide the technical details from the users to provide them with transparency. (2) User in control. The users are always in control of the recommendation process. They can accept and decline the recommendations, and they can start the recommendation and exit the recommendation at any time they want.

Based on these two principles, the implementation was successfully used in the user experiments. It was robust enough to serve all the participants simultaneously during two long haul flight simulations without any problem. The client/server structure distributes the traffic and ensures the scalability, which gives enough confidence that the designed framework and the implemented system are able to handle real flight environments. This answers the question 4 in section 1.4 of chapter 1, with regard to the design and implementation of a proper framework.

6.1.2 Findings

The major findings by statistical analysis of data collected during user experiments are:

(1) Histogram of the heart rate of long haul flight passengers. Although there were a few studies in literature that investigated the heart rate of flight pilots [158], to the best of our knowledge, we are the first to report the histogram of the heart rate of long haul flight passengers.

(2) Effects of music uplifting, keeping and down-lifting of bradycardia, normal and tachycardia state duration in sections. Although there were a few studies in literature that investigated the relation between the heart rate and

the music tempo, to the best of our knowledge, we are the first to report the detailed music uplifting/keeping/downlifting effect with massive data statistical analysis support: the recommended uplifting playlists which are composed by personalized music items with tempos between 100 and 120 BPM reduces the bradycardia state duration from 14.78 seconds in the control group to 6.86 seconds in the test group; the recommended keeping music playlists which are composed by personalized music items with tempos between 60 and 100 BPM increase the normal state duration from 24.66 seconds in the control group to 29.79 seconds in the test group; the recommended down-lifting music playlists which are composed by personalized music items with tempos between 60 and 80 BPM reduce the tachycardia state duration from 13.89 seconds in the control group to 6.53 seconds in the test group.

(3) The relation between controlling the passenger's heart rate at normal and the passenger's stress. A major finding is that by controlling only the passenger's heart rate at normal with music, the user's subjective stress scale and the objective stress level can both be reduced significantly as well.

6.2 Limitations

In the following, the limitations of this PhD project are elaborated from four aspects: model, application field, design and implementation and evaluation.

6.2.1 Model

When designing a biosignal controlled entertainment system to reduce the user's stress. Stress model needs to be an accurate indicator of the user's stress. To this end, the heart rate variability is a more accurate indicator of stress than the heart rate [37]. However, the author did not find the relations between the heart rate variability and music in literatures. Then, heart rate was chosen as the stress indicator. Although we found that by controlling only the passenger's heart rate at normal with music, the user's stress level indicated by heart rate variability can be reduced, the relations between stress, music tempo and heart rate are not known yet.

6.2.2 Application field

Aviation industry is chosen as the application field mainly because this PhD project is sponsored by the European SEAT project in aviation. However, aviation is a very special industry, in which the reliability and safety are supposed to have the top priority. This work paid very little attention to these, but focused only on the functionalities of the heart rate controlled music recommendation system. How and whether this system would have any effect on the reliability and safety of the aircraft are unknown and are out of scope.

The aviation market is also a very special market. It is operated and even dominated by a few large airlines and aircraft manufactures. It is very hard for the outsiders to get the access to the field rules and expertises. One of such examples is the electromagnetic standard for the cabin electrical equipments. During the design of the heart rate controlled music system, because of this difficulty, little attentions has been paid to these field rules. Moreover, due to the intellectual property concerns and the commercial reasons, it was hard to get access to the detail information of the latest commercially available in-flight entertainment systems from companies such as Thales and Panasonic.

6.2.3 Design and implementation

When designing the heart rate controlled in-flight music recommendation system, the complexity of the real world in-flight music system has been reduced. For example, how to seamlessly recommend and log a passenger's personalized music playlists among different aircrafts of an airline, how to manage millions of user profiles over aircrafts' on-board intranets and the airline's on-ground intranet.

Also, due to time limitation and the expertise of this author, the author did not pay much attention to the usability of the system interface. The user interface is implemented with considering "quantities" without considering too much of "quality".

6.2.4 Evaluation

The system developed in this project has never been tested with real passengers in real flights. Experiments were only being done in a simulated long haul flight cabin environment, although much attention and effort has been paid to make it as "real" as possible.

6.3 Future research

Although some progress has been made, more research is needed before the technologies developed within the heart rate controlled music recommendation system could be effectively incorporated into real aircraft cabins. Future work should focus on finding the relations between stress, heart rate and music, more attractive business models for biosignal controlled entertainment recommendation systems, developing more economical yet non-intrusive heart rate sensor technologies.

An interesting avenue for future work that could deepen our result would be to model the relation between controlling the passenger's heart rate at normal and stress (modeled by heart rate variability). This would lead to a new biosignal controlled music recommendation system that adapts music to the stress of the user.

Another interesting research direction is a more attractive business model for biosignal controlled in-flight entertainment systems. The target user group of the heart rate controlled in-flight music system in this project is economy class passengers in long haul flights. Comfort is clearly a main acceptance factor for this group. However, this group is also very sensitive to the price of the flight tickets. This work focused on the technical aspects of the system, and spent few efforts on the business model. It would be interesting to develop a new business model for the heart rate controlled in-flight music system so that both the airline and the economy class passengers can benefit from it.

Another promising research direction for future research is the development of a more economical yet non-intrusive heart rate sensor. The weight and the cost of the sensor have an impact on the acceptance of the airlines. Although the Emfit sensor adopted is non-intrusive and light weighted (300g), its price might be burdensome. One set of Emfit costs more than several thousand and it is still the cheapest non-intrusive heart rate sensor available. Currently, one in-seat in-flight entertainment system offered by Thales or Panasonic is around 8000 Euros per seat. It is hard to imagine that an in-seat sensor costs almost half of it. It seems to be necessary to develop a cheaper, lighter and still non-intrusive heart rate sensor technology.

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Appendix A

Air SEAT club card application form

A.1 Personal Demographic Information

First name: ___________ Middle initial: ___________

Last name: ___________ Nationality: ___________

Profession: ___________ Gender: ○ Male ○ Female

Date of birth (dd/mm/yyyy): ___________

A.2 Music preference

Below are lists of different music genres. For each of the genres, please first check whether it is applicable to you, if it is, indicate the extent to which you like listening to each of them using the scale below.

Jazz	Like	○	○	○	○	○	○	○	Like strongly
		1	2	3	4	5	6	7	
Classical	Like	○	○	○	○	○	○	○	Like strongly
		1	2	3	4	5	6	7	
Religious	Like	○	○	○	○	○	○	○	Like strongly
		1	2	3	4	5	6	7	

Pop	Like	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	Like strongly
Folk	Like	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	Like strongly
Punk	Like	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	Like strongly

Rap/hip-hop	Like	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	Like strongly
Reggae	Like	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	Like strongly
Country	Like	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	Like strongly

Blue grass	Like	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	Like strongly
Rock	Like	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	Like strongly
Heavy metal	Like	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	Like strongly

Blues	Like	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	Like strongly
Funk	Like	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	Like strongly

If your preferred genres of music are not included in the above form, please indicate them below:

____________	Like	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	Like strongly
____________	Like	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	Like strongly

Appendix B

Stress scale questionaire

I am in a crashing airplane with fear of death.

I am involved in a car accident based on my fault.

I am hiding my heavy pain.

I try to cross a street with heavy traffic.
I am watching an exciting movie
I am reading a detective novel.
I am reading the newspaper.

I am solving a crossword puzzle.

I am lying on a sofa and browsing through a magazine.

I am on the green in a forest and dream with open eyes.

Deep, dreamless sleep.

Appendix C

Presence

1. Please rate your sense of being in the test bed, on the following scale from 1 to 7, where 7 represents your normal experience of being in a place.
I had a sense of being in a long haul flight.

Not at all	○	○	○	○	○	○	○	Very much
	1	2	3	4	5	6	7	

2. To what extent were there times during the experience when the test bed became the "real long haul flight" for you, and you almost forgot about the "real world" of the laboratory in which the whole experience was really taking place?
There were times during the experience when the virtual "long haul flight" became more real for me compared to the "real flight"...

At no time	○	○	○	○	○	○	○	Almost all the time
	1	2	3	4	5	6	7	

3. When you think back about your experience, do you think of the test bed more as images that you saw, or more as somewhere that you visited? Please answer on the following 1 to 7 scale:
The test bed seems to me to be more like...
1. Images that I saw ...7. Somewhere that I visited.

Images that I saw	○	○	○	○	○	○	○	Somewhere that I visited
	1	2	3	4	5	6	7	

4. During the time of the experience, which was strongest on the whole, your sense of being in the flight, or of being in the real world of the laboratory?
I had a stronger sense of being in...
1. the real world of the laboratory ... 7. the virtual reality of the flight.

Real world of the laboratory	○	○	○	○	○	○	○	Virtual reality of the flight
	1	2	3	4	5	6	7	

5. During the time of the experience, did you often think to yourself that you were actually just sitting in a test bed or did the long haul flight overwhelm you?
During the experience I often thought that I was really sitting in the test bed.... 1. Most of the time I realized I was in the test bed ... 7. Never because the long haul flight overwhelmed me.

Most of the time I realized I was in the test bed	○	○	○	○	○	○	○	Never because the long haul flight overwhelmed me
	1	2	3	4	5	6	7	

Appendix D

Hearing Ability

1. Do you have any difficulty with your hearing?

○ No ○ Yes

2. Do you find it very difficult to follow a conversation if there is background noise such as TV, radio, Telephone conversations, children playing?

○ No ○ Yes

3. How well do you hear someone talking to you when that person is sitting on your RIGHT SIDE in a quiet room (Please circle the applicable answer)?

○ With no difficulty ○ With slight difficulty

○ With moderate difficulty ○ Can not hear at all

4. How well do you hear someone talking to you when that person is sitting on your LEFT SIDE in a quiet room (Please circle the applicable answer)?

○ With no difficulty ○ With slight difficulty

○ With moderate difficulty ○ Can not hear at all

Samenvatting

Door de explosieve groei van entertainment materiaal en de alomtegenwoordige toegang hiertoe door middel van allerlei mobiele of vaste apparatuur zijn aanbevelingsdiensten een onmisbaar gereedschap geworden om gebruikers te helpen geschikt entertainment te vinden op een gegeven plaats en tijd. We voorzien dat door de integratie van biologische ingangssignalen in het aanbevelingsproces gebruikers niet alleen geholpen zullen worden bij het vinden van interessant entertainment materiaal, maar dat hierdoor bovendien hun niveau van welbevinden zal kunnen toenemen.

Het doel van dit project was een door biologische signalen gestuurd aanbevelingssysteem voor entertainment te ontwikkelen dat het niveau van welbevinden van een gebruiker verhoogt door zijn stress niveau te verminderen. Het project tracht hierbij op twee punten een bijdrage te leveren op het gebied van aanbevelingssystemen. Het eerste punt is het mechanisme om biologische signalen op niet hinderlijke wijze in het aanbevelingsproces te betrekken. Het tweede is de strategie achter het door het biologische signaal gestuurde aanbevelingproces dat dient om de stress te verminderen.

Een op basis van hartslag gestuurde aanbevelingsdienst voor muziek op lange afstandsvluchten is gekozen als applicatie domein. De hypothese is dat de hartslag van de passagier tijdens een lange afstandsvlucht afwijkt van de normale waarden, vooral tengevolge van de ongewone cabine omgeving. Door een aanbevelingssysteem voor muziek nu zo te ontwerpen dat op basis van hartslag aangepaste persoonlijke muziek afspeellijsten aan de passagier kunnen worden aanbevolen, kan de hartslag van de passagier worden verhoogd, dan wel verlaagd naar een normaal niveau, of ook op een normaal niveau worden gehandhaafd, waardoor de stress wordt verlaagd. Op basis van deze hypothese zijn vier onderzoeksvragen geformuleerd.

Na de literatuurstudie ging het project in hoofdlijnen door drie fasen: het ontwerpen van een algemeen raamwerk, de implementatie van het systeem, en het doen van een gebruikersonderzoek om de geformuleerde researchvragen te beantwoorden.

Gedurende de ontwerpfase van het raamwerk, werd de hartslag om te beginnen gemodelleerd door middel van de drie toestanden: bradycardia, normaal, en tachycardia. De bedoeling van het raamwerk is om, wanneer de hartslag van de gebruiker hoger of lager is dan normaal, de hartslag te normaliseren door het systeem een passende persoonlijke muziek afspeellijst te laten aanbevelen, en om anders de hartslag op het normale niveau te handhaven. Het raamwerk verenigt het concept van context afhankelijke adaptieve systemen, gebruikersprofielen, en de methoden om met behulp van terugkoppeling in een regelsysteem de hartslag aan te passen door het gebruik van muziek.

In de terugkoppellus werden de afspeellijsten samengesteld met. Binnen het raamwerk wordt de gebruiker echter in staat gesteld om deze aanbevelingen te verwerpen en met de hand zelf zijn of haar favoriete muziek te selecteren. Gedurende dit proces slaat het systeem de communicatie over en weer tussen systeem en gebruiker op, om later de meest recente voorkeuren van de gebruiker op het gebied van muziek te leren.

Het ontworpen raamwerk werd gemplementeerd m.b.v. een platform-onafhankelijke software architectuur. Deze architectuur heeft vijf lagen van abstractie. De onderste laag, die van de hulpbronnen, omvat de muziekbron, de hartslagsensoren, en de informatie over het gebruikersprofiel. In de tweede laag wordt de toegang tot de hulpbronnen geregeld. De regelcomponenten in deze laag besturen de hulpbronnen in de onderste laag en bemiddelen de toegang van de hoogste lagen tot de hulpbronnen. De derde laag is een database, die fungeert als medium voor gegevensopslag. De vierde laag dient voor de adaptieve sturing, en omvat de opslag van de terugkoppelingsresultaten voor de gebruiker, het redeneersysteem, en de leercomponent voor de gebruiksvoorkeuren. Op de toplaag vinden we de gebruikersinterface. In deze architectuur zijn de verschillende lagen, evenals de componenten van deze lagen onderling slechts los gekoppeld, waardoor de flexibiliteit gewaarborgd blijft.

Het gemplementeerde systeem werd benut om in gebruikerstesten de hypothese te toetsen. De experimenten simuleerden de lange afstandsvluchten van Amsterdam naar Shanghai, gebruikmakend van hetzelfde tijdschema als de KLM vluchten. Twaalf proefpersonen werden uitgenodigd om aan de experimenten deel te nemen. Zes werden aan een controle groep toegewezen en (de) anderen aan een test groep. In vergelijking met het gewone entertainment systeem voor de controle groep werd de test groep bovendien uitgerust met het door hartslag bestuurde aanbevelingssysteem voor muziek.

De experimentele resultaten bevestigden de hypothese en beantwoordden de onderzoeksvragen. De hartslag van de passagiers wijkt inderdaad af van de normale waarden. In onze experimenten was de hartslag van de passagiers gedurende 24.6% van de tijd in de bradycardia toestand en gedurende 7.3% van de tijd in de tachycardia toestand. De aanbevolen hartslagversnellende muziek bracht de duur van de gemiddelde bradycardia toestand terug van 14.78 seconden in de controle groep tot 6.86 seconden in de test groep. De aanbevolen hartslag handhavende muziek verhoogde de gemiddelde tijdsduur van de normale toestand van 24.66 seconden in de controle groep tot 29.79 seconden in de test groep. De aanbevolen hartslagverlagende muziek bracht de tijdsduur van de gemiddelde tachycardia toestand terug van 13.89 seconden in de controle groep tot 6.53 seconden in de test groep. In vergelijking met de controle groep werd de stress van de test groep significant verlaagd.

Summary

With the explosive growth of entertainment content and the ubiquitous access to them via fixed or mobile computing devices, recommendation systems become essential tools to help the user to find the right entertainment at a given time and location. I envision that integration of the biosignal input into the recommendation process will not only help users to find interesting content, but will also be instrumental in increasing their comfort level.

The goal of this project was to develop a biosignal controlled entertainment recommendation system that increases the user's comfort level by reducing his or her level of stress.

This project aims to contribute to the field of recommendation systems on two points. The first is the mechanism to embed the biosignal non-intrusively into the recommendation process. The second is the strategy behind the biosignal controlled recommendation to reduce stress. Heart rate controlled in-flight music recommendation is chosen as the application domain. The hypothesis is that the passenger's heart rate deviates from the normal due to the unusual cabin environment during the long haul flight. By properly designing a music recommendation system to recommend heart rate controlled personalized music playlists to the passenger, the passengers' heart rate can be uplifted, down-lifted back to normal or kept within the normal range, thus reducing his or her stress. Four research questions have been formulated based on this hypothesis.

After the literature study, the project went mainly through three phases: framework design, system implementation and user evaluation to answer these research questions.

During the framework design phase, the heart rate was firstly modeled as the states of bradycardia, normal and tachycardia. The objective of the framework is that, if the user's heart rate is higher or lower than the normal heart rate, the system recommends a personalized music playlist accordingly to transfer the user's heart rate back to normal, otherwise to keep it at normal. The adaptive framework integrates the concepts of context adaptive systems, user profiling, and the methods of using music to adjust the heart rate in a feedback control system. In the feedback loop, the playlists were composed. Yet, the framework allows the user to reject the recommendations and to manually select the favorite music items. During this process, the system logs the interactions between the user and the system for later learning the user's latest music preferences.

The designed framework was then implemented with platform independent

software architecture. The architecture has five abstraction levels. The lowest resource level contains the music source, the heart rate sensors and the user profile information. The second layer is for resource management. The manager components in this layer manage the resources of the first layer and modulate the access from upper layers to these resources. The third layer is the database, acting as a data repository. The fourth layer is for the adaptive control, which includes the user feedback log, the inference engine and the preference learning component. The top layer is the user interface. In this architecture, the layers and the components in the layers are loosely coupled, which ensures flexibility.

The implemented system was used in the user experiments to validate the hypothesis. The experiments simulated the long haul flights from Amsterdam to Shanghai with the same time schedule as the KLM flights. Twelve subjects were invited to participate in the experiments. Six were allocated to the control group and the others were allocated to the test group. In addition to a normal entertainment system for the control group, the test group was also provided with the heart rate controlled music recommendation system.

The experimental results validated the hypothesis and answered the research questions. The passenger's heart rate deviates from normal values. In our user experiments, the passenger's heart rate was in the bradycardia state 24.6% of time and was in the tachycardia state 7.3% of time. The recommended uplifting music reduces the average bradycardia state duration from 14.78 seconds in the control group to 6.86 seconds in the test group. The recommended keeping music increases the average normal state duration from 24.66 seconds in the control group to 29.79 seconds in the test group. The recommended downlifting music reduces the average tachycardia state duration from 13.89 seconds in the control group to 6.53 seconds in the test group. Compared to the control group, the stress of the test group has been reduced significantly.

Curriculum Vitae

Hao Liu was born in Shanxi, China on 11th August 1973. After graduating from the computer science and engineering department of Southwest Jiaotong University, he worked as an electrical engineer at the R&D department of Sifang company, China South Locomotive & Rolling Stock Corporation Limited. He continued his study again at Southwest Jiaotong University from 1999. He graduated and received a master of computer science degree in 2002. After that, he worked as a researcher at Institute of Computing Technology, Chinese Academy of Sciences. Since September 2006, He has been a PhD candidate of Designed Intelligence Group, Industrial Design Department, Technical University of Eindhoven.