Automatic Music Accompaniment Technology Applied to Recreational Singing Activities at Long-Term Health-Care Facilities

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Abstract. This paper presents an automatic music accompaniment technology (the implemented system name is "Eurydice") applied to recreational singing activities at long-term health-care facilities. We devised how to create standard MIDI files so that accompaniment performance progresses sequentially even if the player hits any keys on a digital piano. In contrast to the usual situation that performances are matched to a music score, this technique makes performances enjoyable even for facility residents who lack ability to read music scores or performance skill and technique. It seems that the facility residents actively participate in the performance and the interaction with others is activated. We also implemented a function of automatically adding special track for tempo control for Eurydice, and used wireless music keyboard to give all participants the opportunity to perform easily and safely. It is considered that this system is effective in rehabilitation and elementary music education.

Keywords: automatic music accompaniment technology, facility residents, recreational singing activities, digital piano, standard MIDI file

1 Introduction

Long-term care geriatric health facilities in each country are diverse[3, 7, 9, 12]. For example, in the Netherlands almost all of such facilities are public, and conversely in the UK private facilities occupy great percentage.

In Japan, long-term care geriatric health facilities allow care recipients who need medical care and functional training (rehabilitation) to live in. Such facilities provide services such as supplementary meals, bathing, changing clothes, disposal of excretion, and medical care by doctors and nurses. A major characteristic of the facilities is that the facility residents carry out substantial rehabilitation by physiotherapists and occupational therapists, and practical rehabilitation

using walkers and wheel chairs. Since the facilities have an intermediate role between the hospital and home, rehabilitation assuming home return is performed, and therefore the possible admission period is short (about 3 months to about 1 year). In addition, not only living into the facility but also a short stay or a going to the facility is possible, and the system leads to a reduction in the burden on caregivers.

It is possible to aim for recovery to daily life by full scale rehabilitation guided by occupational therapists or physical therapists. Furthermore, because the medical system is substantial, facility residents can receive prompt response by experts in case of emergency. Since a family of a care recipient can reform the house so that it is easier to care for at home when the care recipient lives in the facility, it can be utilized as a preparation period for home care. Using such facilities also has some merits that the nursing-care insurance can be applied and the fee is cheaper than the privately operated facility.

On the other hand, if it is judged every three months that the facility residents can live at home, they can not live in the facility continuously. Furthermore, during the entrance period, rehabilitation is the main focus of living, thus each facility resident has less free time and it tends to have fewer events and recreation. For rehabilitation or preventive long-term care, various computer technologies are used such as virtual reality[6], and game systems[4, 11].

In such circumstances, Sakai, as a volunteer, has carried out music recreation at such facilities. In this article, we explain participatory recreational singing activities using an automatic music accompaniment system *Eurydice*, and show the interaction between residents of long-term care geriatric health facilities (hereinafter abbreviated as facility residents) and Eurydice.

In Section 2 we present automatic music accompaniment technology, and in Section 3 we introduce Sakai's preceding practice. Section 4 and 5 illustrate application of Eurydice and practice example. Section 6 and 7 describe discussion and conclusions.

2 Automatic music accompaniment system "Eurydice"

The conventional music accompaniment system only performs mechanically at the set tempo, and it is necessary for the player to adapt to the accompaniment, that is, it is kind of karaoke. In contrast, the automatic music accompaniment system Eurydice which we have been developing is completely different from the convention system, and Eurydice adapts to the performance of the player[8]. Unlike improvisation system such as Biles' "GenJam" [2] and Kalonaris' "Dory" [5], Eurydice performs accompaniment part based on the given music score. Fig. 1 shows the system conceptual diagram of Eurydice. A player performs using a MIDI instrument. The MIDI instrument outputs MIDI signals to Eurydice. The score following section estimates both a score position and a playing tempo of human performance using reference MIDI data which are given as SMF (standard MIDI file). The accompaniment performance section outputs MIDI signals of accompaniment performance to a MIDI device. In the typical use, human

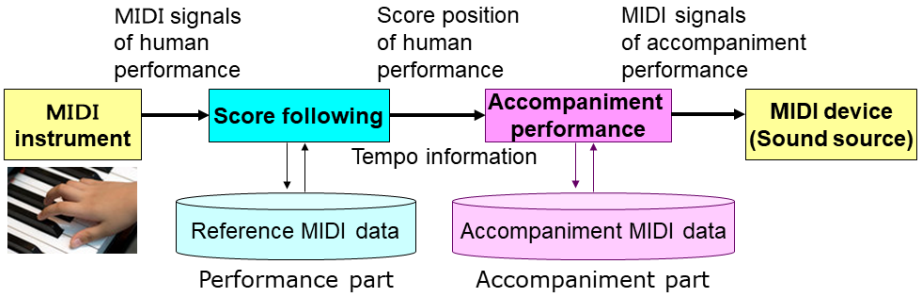

Fig. 1. System conceptual diagram of Eurydice.

plays a melody part, and Eurydice performs an accompaniment part. For example, in a piano sonata, human is in charge of a right hand part and Eurydice is assigned a left hand part. In Eurydice, the player can freely choose playing part. Therefore, in a left hand practice, human is in charge of a left hand part and Eurydice is assigned a right hand part. Moreover, in a piano concerto, human plays piano part with both hands and Eurydice performs all other orchestral instrument parts.

A deterministic performance is accurate pitch and tempo, uniform note length, and straight progression. On the other hand, human performances are not uniform, even if a player performs the same music score. There are various differences every time, which are called performance indeterminacy. The performance indeterminacy can occur intentionally or unintentionally and typical causes are as follows:

1. Subtle variation of onset time
2. Tempo
3. Loudness and articulation
4. The number of notes and pitches on grace notes
5. Performing mistake
6. Jump (repeat or omission)

In this case, the performance indeterminacy which includes expressive nuances means the opposite of a mechanical and uniform performance. Therefore it is not easy to estimate the score position for performances including the above indeterministic elements even if the music score is given in advance.

Assuming that a performance is performed from the music score, estimating the score position from the performance is an inverse problem. Eurydice solves this inverse problem by modeling a player's performance using hidden Markov model (HMM) and estimating the score position by stochastic inference. Fig. 2 shows a conceptual diagram of HMM for score following. It is assumed that each note or chord is considered as one state,[1] and notes corresponding to the music score are output from each state, however other chords are also output with a

[1] Sounds pronounced within 35 ms are regarded as chords.

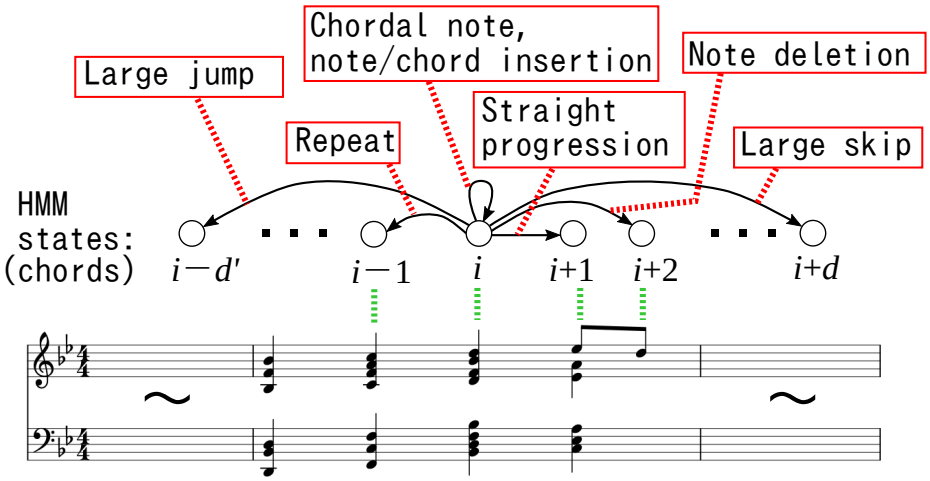

Fig. 2. Conceptual figure of HMM for score following.

low probability. As a result, a pitch error can be absorbed. For example, at a state i in Fig. 2, if a player performed E5 instead D5, it is assumed that it was also output from state i with a low probability. For the state i corresponding to the current score position, let the state of the next chord be $i + 1$. Therefore, in the case of straight progression, the state number i will increase one by one. Eurydice treats the chord as a self transition, that is, consider that plural pitches are outputted from the same state. Likewise, extra notes by insertion mistake can also be absorbed by handling them as outputs from self transition. In a note deletion, a state transition arise from current state i to two state away $i + 2$, and consequently the chord of $i + 1$ will not be performed. A repeat is dealt with transition to state $i - 1$. Moreover, in a forward large skip or backward large jump, state changes to $i + d$ or $i - d'$. Hence, Eurydice estimates the score position of human player, and performs accompaniment part corresponding score position.

In order to match with the performance of the player, it is necessary to estimate not only the score position but also the tempo. Tempo is the speed with respect to real time of musical score time, Let τ be a variable representing musical score time, and t be real time. Tempo r is expressed by equation (1).

$$r = \frac{\delta\tau}{\delta t} \ . \tag{1}$$

The local tempo r_m is calculated by equation (2).

$$r_m = \frac{\tau_{m+1} - \tau_m}{t_{m+1} - t_m} \ , \tag{2}$$

where the denominator equals inter-onset interval (IOI) between the m-th and $(m + 1)$-th note and the numerator is note length on the musical score for each

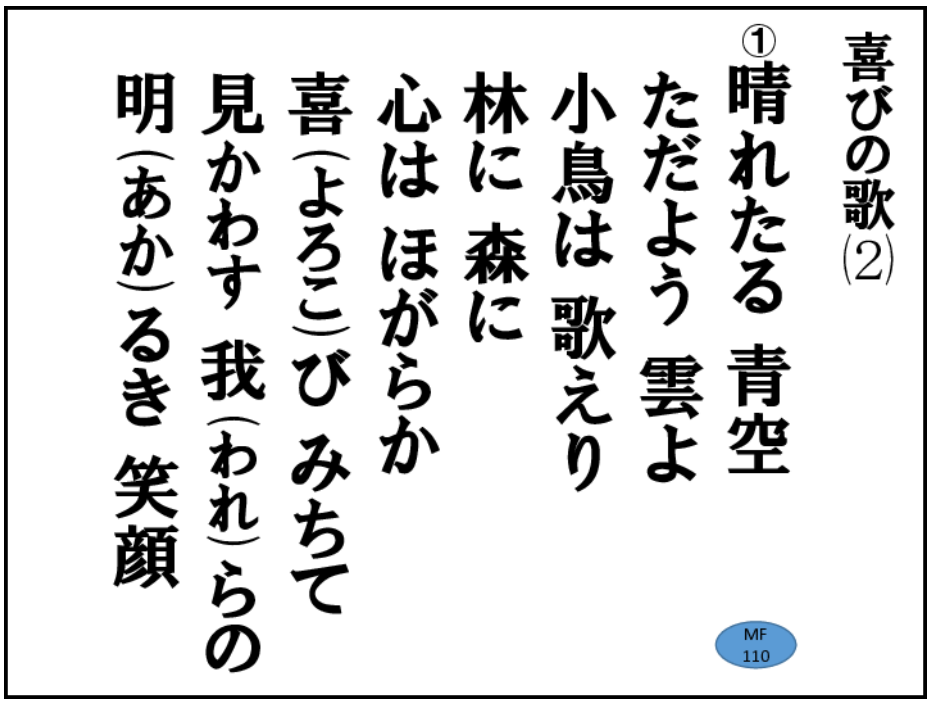

Fig. 3. Example of song slide which is "Ode to Joy" from Beethoven's Symphony No.9. The lyrics are written in Japanese in vertical written.

note. Furthermore if the m-th onset time is known, the $(m+1)$-th one can be predicted.

Eurydice also has two performance modes. One is "waiting mode" that Eurydice waits the next note to be performed by player. In this mode, state transition of HMM is triggered by only MIDI input signal. The other one is "non-waiting mode" that it is allowed to progress sequentially without waiting for the player's performance while permitting any jump. In non-waiting mode, state transition is always occurred based on tempo information or MIDI input signal, and continue performing accompaniment part even if player stop to perform.

Because Eurydice plays according to SMF, it allows even difficult musical pieces that player can not play. Furthermore, very difficult music pieces that people can not play are also likely to be composed on the assumption of using Eurydice.

Fig. 4. Scene that the facility residents are singing.

3 Preceding example: recreational singing activities by using MIDI karaoke

Sakai has performed music recreation at the elderly care facility for nursing care as a volunteer in Atsugi city. In 2012 and 2013 he served as an assistant for recreational singing activities by piano accompaniment at the elderly facilities. In 2014, the instructor of recreational singing activities became unable to participate due to various reasons, and asked Sakai to execute for substitution. Therefore Sakai started singing activities using a singing accompaniment system (karaoke version) devised by himself. Up to the present, the number of activities has exceeded 500 at the Atsugi City Seiwakai-related facilities and over 200 at others.

As a way of recreational singing activities, he creates slides of lyrics using Microsoft PowerPoint and displays it on the large LCD TV at the facility. Accompaniments of songs created as SMF (Standard MIDI File) are embedded in PowerPoint, and performed using Windows Media Player. Fig. 3 shows an example of slide which includes blue ellipse link of accompaniment performance with BPM = 110.

Fig. 4 shows the scene that facility residents are singing. Many residents use wheelchair. In addition, Sakai not only makes the facility residents to sing songs

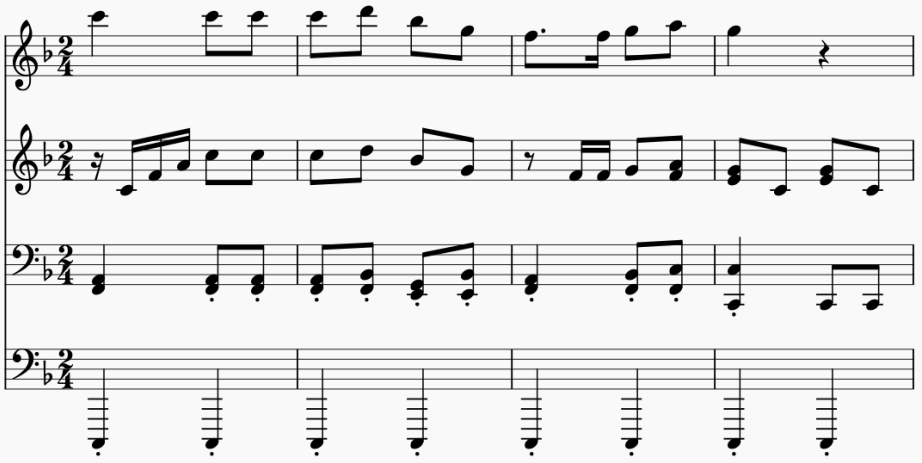

Fig. 5. Score example of SMF (Village Festival). Notes of low pitch C1 are arranged in the last music part which is added to control tempo by hitting any piano key.

but also explains the meaning of lyrics and the historical background. Therefore, the residents understand the songs deeply, remember the old days, or shed tears with strong emotions.

Sakai uses his handmade indication stick which is a thin wooden rod attached a wooden ball rolled a red yarn. The reason for using the stick is that when he used the laser pointer, many facility residents asked him "What is that" respectively, and the atmosphere in the venue was thrown into a commotion and then the recreational singing activities were no longer established. No confusion has occurred in any facility after using the current stick.

4 Application of Eurydice for residents of a long-term care health facility

4.1 Recreational Singing Activities with Eurydice

As mentioned in Section 2, Eurydice has a powerful score following function that tracks indeterminate performances. If the player can perform the melody a bit while making a mistake, Eurydice follows the proper performing position in music score. However, most of the facility residents have no experience of performing the piano and many people can not even read the music score (staff notation score). Even if they have such skills, movements of their fingers may decline with age. Therefore, we devised to progress accompaniment performance sequentially regardless of performances.

To obtain tempo information from the player, we prepare a special track in the SMF in addition to the melody and accompaniment part, and arrange the low note C1 in the 88 key piano. For example, as shown in Fig. 5, quarter notes

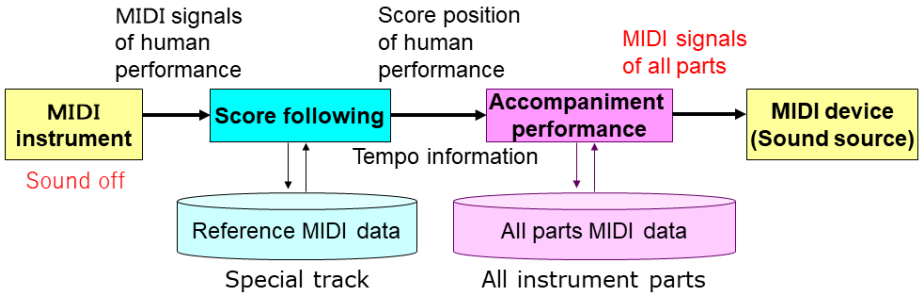

Fig. 6. System conceptual diagram of Eurydice in the case of using special track.

are arranged if the music is in four-four time. This pitch is actually out of the range of the pitch dealt with the music keyboard KORG microKEY–25 which has 25 keys used the recreational singing activities. The pitch range of this music keyboard is from C3 to C5. Hence no matter what key on the music keyboard is touched, the pitch C1 can not be performed. However, in fact, it is effective to this study as the following.

Eurydice expects the next note of the current score position if it is a straight progression. However, the pitch of the MIDI signal actually inputted from the music keyboard is always erroneous for C1 pitch in special track. At this time, since the pitches performed by the player on the musical score are all C1, it is unclear that which position of C1 is most justifiable. In this condition, although Eurydice calculates a uniform probability in order to jump to all the note positions, the probability of the next note is the highest. Particularly as a large pitch error occurs, the sequentially progressing note position is estimated as a new score position. If this is a pitch that can be performed on a music keyboard (or slightly off the range), it is possibility presumed a re-performance at the same note position or a jump to the position before or behind the score. In this study, taking advantage of occurring large pitch errors by using a compact music keyboard with limited pitch range, the music sequential progression is realized even if any keys are depressed.

Fig. 6 shows the concept of Eurydice in the case of using special track. The output sound of an input MIDI instrument (digital piano) is set to turn off, or a music keyboard that does not have a sound source like KORG microKEY–25 is suitable. This is the characteristic of digital piano. Acoustic pianos can not be used under such condition. Eurydice estimates a score position of player performance by doing score following for the special track, and outputs the MIDI signals of all parts of that score position which include melody part. j

4.2 Automatic addition of special track for tempo control

As mentioned in the previous section, it is found that Eurydice can be controlled so that music can be progressed in order no matter which key is pressed by adding special tracks to SMF and arranging same pitch successive notes for

instructing tempo by hand. However, adding tracks and editing them to arrange such notes throughout the whole song requires time and effort (Nevertheless, Sakai has already edited more than 150 songs which are included the special track). Therefore, we expanded the function of Eurydice and implemented to add and remove special tracks after loading SMF.

Eurydice currently implements it using the cross platform development environment "Qt". In Qt, parts such as push buttons, combo boxes, sliders are prepared, and they can be easily placed in the window. The check box is used for the operation of the special track in this time. If the check is on, add a special track next to the last track and delete it if the check is off. Consequently, for the same song, player can switch easily how to use between usual performance and giving only tempo information. Facility residents, staffs, and volunteers who can play melody can use Eurydice's normal music accompaniment, and a person who can not play the piano can provide tempo information to Eurydice like a conductor by just hitting any keys.

SMF contains information on time signature. Therefore, if the denominator of the time signature is 4, quarter notes are arranged. Each note length t_{note} is the delta time t_{delta} obtained from the SMF header, and the notes of the numerator n_{num} of the beat per bar are arranged.[2] In addition, when the denominator of the time signature is 8, we usually tick a beat every three eighth notes, hence we calculate equation (3) with a dotted quarter note as a note length of one beat and $\frac{n_{num}}{3}$ notes per bar are arranged.

$$t_{note} \;=\; t_{delta} \times \frac{3}{2} \;. \tag{3}$$

Eurydice calculates the total song length t_{whole} when loading SMF. From this, the notes are arranged continuously while the sum of the time lengths $t_{sum} = \sum t_{note}$ of the added note sequence satisfies Equation (4).

$$t_{sum} \;\leq\; t_{whole} \;. \tag{4}$$

For any note, the tone pitch is set to the note number `0x00`, and the velocity is given as `0x7F` (127). As for the pitch in MIDI, note number of note name C1 is `0x18` (24), hence `0x00` corresponds to C–1 in terms of pitch name. Because the note name C–1 is about two octaves lower than A0 (note number `0x15`) which is the lowest pitch of the 88 keys piano, a commercially available standard music keyboard can not perform the note of C–1 pitch. As mentioned in the previous section, it is important in this study that "the pitch that can not be performed".

First, the window of Eurydice immediately after loading SMF is shown Fig. 7. Eurydice automatically determines the part allocation as an initial state so that the first track is performed by a person and all other tracks become accompaniment parts. Second, the state in which Eurydice is in charge of performing all

[2] Delta time indicates the resolution per quarter note. For example, assuming that the resolution of whole note is 1920, a value `0x01E0` (480 = 1920 / 4) is stored in the delta time field of the SMF header.

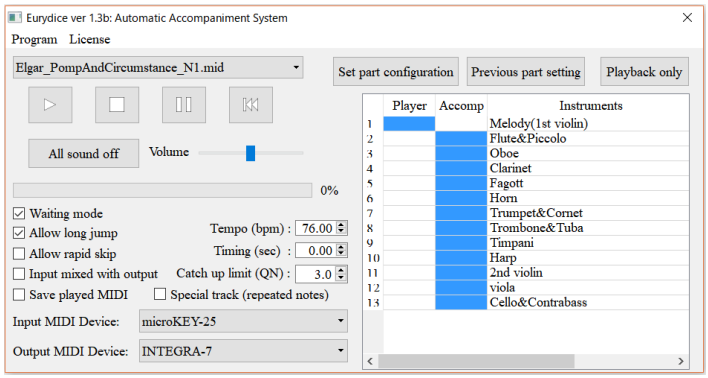

Fig. 7. The window of Eurydice right after loading SMF.

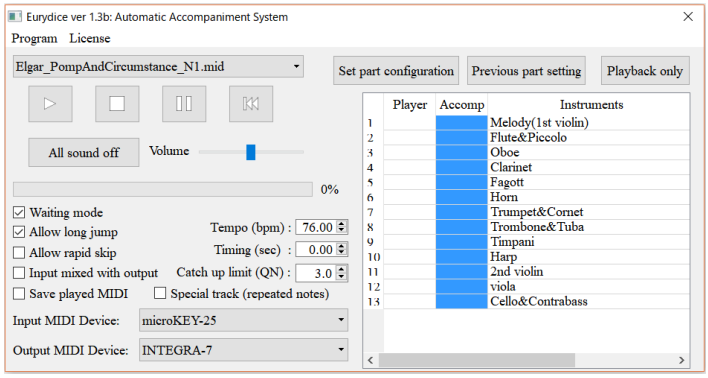

Fig. 8. The state of “Playback only” mode.

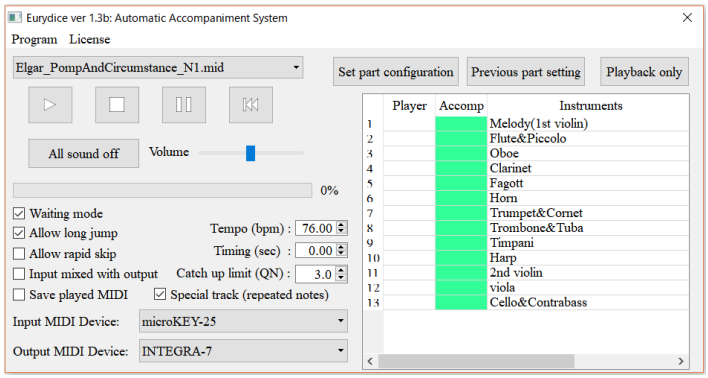

Fig. 9. The state that the special track is added.

Fig. 10. Aspect of perform while marching in place by using a wireless music keyboard. Sakai made an auxiliary tool combined a strap and a mesh panel for hanging microKEY–25 from his shoulder.

the tracks is shown in Fig. 8. In this case, Eurydice performs all the instrument parts as accompaniment parts regardless of human performance, namely this is karaoke state. This is the "Playback only" mode prepared for checking the contents of the music. Third, Figure 9 shows the state that the check box of "Special track" is checked. Although Eurydice is responsible for all the music parts as same as "Playback only" mode, the color of the part selection button is green. It indicates that the special track is added inside Eurydice.

4.3 Utilization of wireless music keyboard

In the past efforts, we used KORG microKEY–25 from the viewpoint of portability as mentioned above. This music keyboard connects PC through USB connection and has excellent characteristics such as no power cable for driving, and extremely light. According to the USB cable standard, the longest cable length between devices is 5 meters long, while a cable with active repeater is up to 30 meters long is commercially available. In this way, extending the USB cable can let the music keyboard reach the music recreation participants who are away from the PC. However, since participants sit in chairs or use wheelchairs, the music recreation venue is dense. Therefore, in consideration of safety, it is necessary to prevent the cable from being caught by feet or not to be wrapped around bodies or wheelchairs.

On the other hand, we have recently used KORG microKEY Air–25 which is wirelessly connected by Bluetooth. Its effective distance is maximum 5 meters long, and two AA-sized batteries drive the music keyboard. Up to now, only

Fig. 11. Aspect of performance by facility resident.

the front row participants around the PC performed on the music keyboard. Although it is difficult for some participants to express emotions and volition in front, in fact they are interested in the performance (they often sit backward in the hall). Utilization of wireless music keyboard is now possible to give all participants the opportunity to perform easily and safely.

In addition, Fig. 10 shows the state of marching in place and performing microKEY Air–25 to control the music tempo for Eurydice. Player can move freely within the reach of the Bluetooth signal without wrapping or hooking the USB cable on the body or leg. Player can also perform at own pace depending on the march in place and can check with ears while listening to the song whether a constant tempo is ticked. From these factors, it is considered that this system is effective in rehabilitation.

5 Practice example

Fig. 11 shows an aspect of performing the keyboard by a facility resident. Facility residents expressed facial expressions of surprise and pleasure on their face. One of the residents had been longing for many years playing the piano and was moved to tears when the resident was able to play the piano. Residents who usually are not good at talking and singing also wanted positively to play the piano with Eurydice. A resident, who is from a farmhouse and whose fingers are bent, pushed both a key and the next key at the same time, but it is no problem for Eurydice. Other residents suffering from rheumatism also performed with only one finger or moved the fingers hard. Favorable opinions such as “This is very fun” and “It seems that I am performing all instruments” were obtained

from the facility residents who actually experienced the performance. In addition, we could see scenes that the performed residents were said from other residents such as "Your performance was excellent" and "You can perform very well". This study is useful not only to induce the enjoyment and interest of music at the individual level, but also to activate mutual communication among facility residents.

6 Discussion

Up to now, we have not been able to quantitatively evaluate this system. Facility staff does not permit us to measure vital signs such as blood pressure and brain functions due to protection of personal information. Therefore, we intend to have facility staff understand that we do not disclose personal information according to research ethics. At a minimum, we will obtain a systematic qualitative assessment. It may be difficult to obtain answers from facility residents who are progressing dementia, however an interview will be effective instead a paper questionnaire. In addition, we will invite staffs and families of facility residents to the singing recreation and listen to opinions about changing aspects of facility residents.

Some players performed a melody rhythm instead its beat if players know the melody rhythm. We will implement a switch that can choose that player performs which of the cues.

It takes 30 minutes to create lyrics and 2 hours to prepare SMF for this study. Particularly, it takes time editing SMF for volume adjustment. To adjust the volume balance between the melody part and accompaniment part, we add dynamics signs to SMF by using Finale which is made by MI Seven Japan Company, and then replay the SMF and modify the volume balance again and again. Therefore, if the volume adjustment for each part can be executed while performing on Eurydice, the work efficiency will be remarkably improved.

Currently Eurydice just lists all the SMFs that are under the folder named "MIDI" in the folder (directory) where the executable file exists. We have already prepared SMFs over 500 music pieces, and it is difficult to choose the desired music from among them. On the other hand, music choice will be easily by implementing a file selection dialog and a search function, and storing SMFs according to genres and music titles respectively. Since there is also convenience for the conventional music selection method, we plan to implement both music selection methods.

By the performances in recreational singing activities that facility residents actively participate, it can be expected effects such as rehabilitation of body functions centered on the fingers and prevention of dementia due to stimulation to the brain by key tactile and rhythm feeling. Music therapy [1, 10] reduces mental disorders through not only singing, but also laughing and conversation with others, contributes to improving and stabilizing the physical (brain function, internal organs function) and mental aspects, and improvement on both sides appears as a synergistic effect. Currently, we target performance in the state of

Fig. 12. Performance example in the bed.

being awake, in the future, we will study the case of a bedridden situation as shown in Fig. 12.

Although there is almost no problem in case that facility staffs can operate computers, if not, it is difficult to spend time to be learned how to operation owing to various jobs. For that reason, it can be estimated that recreational singing activities will be also carried out mainly by volunteers in the future. In order to continuously and widely deploy this study, it is necessary to train volunteers, for example, persons who have reached the retirement age will be valuable human resources.

Until now, recreational singing activities with Eurydice has been applied at the Long-Term Care Health Facility. We also started recently applying this system to preschool children such as kindergartens, nursery schools, day care centers. As the music progresses as long as player hit the keyboard, even for young children who can not read the score can enjoy the performance easily, and it is expected to be interested in music. In fact, Sakai went to nursery schools a few times. Children were interested in Eurydice and played happily. For more details on this effort, we are planning to announce it on another occasion.

7 Conclusions

This paper presented automatic music accompaniment technology applied to recreational singing activities at long-term health-care facilities. In the recreational singing activities up to now, residents of the facility sang with *karaoke* music. In this study, by using an automatic music accompaniment system *Eurydice*, the residents could take greater pleasure than by using former simple

karaoke system, and activate communicating with other residents. We also implemented the function to automatically add a special track for tempo control, and expanded the area of performance location using wireless music keyboard.

As future works, we will solve several problems described in Section 6 such as controlling volume of each instrument on Eurydice, and improving selection method of music piece. In addition, although currently we can not obtain quantitative evaluation because the facility staffs do not allowed us to measure biological signals of the facility residents from the viewpoint of privacy, we will try to solve this issue. Furthermore, we will try to apply Eurydice to bedridden persons and preschool children, and training volunteers for music therapy. We would like to expand the scope of application and contribute to social welfare and elementary music education.

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