Integrating a Robotic Drummer with Live Musicians

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***Abstract*-Traditional North Indian religious music has, for the most part, used traditional drums like the tabla. This article describes the work that has been done thus far in integrating a robotic drummer in a music band. It illustrates a user centred design approach for the creation of an interface to be used by musicians working with the robot. The interface is designed to be used during a training session for the creation of a tabla accompaniment piece with little additional training or technical knowledge. The first iteration of the design was created and formative testing was conducted. Users were successfully able to use the interface to complete a series of tasks and recommendations were gathered for improving the next iteration.**

Keywords- Human-Robotic Interaction; Robotic Drumming; Tabla

I. INTRODUCTION

Since robotic applications were introduced in the domestic environment, robots are constantly being introduced and integrated into new areas. The International Federation of Robotics has estimated that the number of service robots sold for personal and domestic use rose by 15% from 2010 to 2011 [1]. Increasingly, robots are being placed in environments where they have to interact, on some level, with humans.

The field of human – robot interaction has now become well established [2] but remains a diverse area because of the very different nature of the interactions [2, 3]. Despite this, there have been efforts to identify commonalities in interaction models for the purpose of comparative analysis and to help develop design methods [4, 5].

One area that has not had much exposure to robotics specifically or technology generally, is traditional North Indian religious music. Whereas drum machines and other synthesized percussion instruments are a common part of several popular musical genres [6], similar synthetically produced percussion sound systems have failed to garner the same level of acceptance in North Indian orchestras. The inherent complexity of the tabla, the instrument which is to be synthesized is the major obstacle [7]. The variety of sound which can be produced is so complex that, in traditional Indian music, the sound is classified into no less than 8 separate syllables [8]. Electronically produced sounds remove any of the visual cues that music groups or orchestras use to convey timing and mood. Further, when used in concert performances electronic music is devoid of any visual connection, the audience may have with the sounds produced, resulting in a less engaging performance [9]. Such a device may also add to the enjoyment of the performance by the audience due to its novel nature, which is desirable as it is intended for entertainment purposes.

The use of a robotic player using an actual instrument can provide visual connection with sound. Such a system would allow for the convenience of an electronically synthesized percussion beat, while avoiding the difficulty associated with reproducing the tonal quality of an actual instrument. The other musicians in the orchestra, more specifically the singer however, must be comfortable interacting and performing with the device. To facilitate the introduction of robotic devices in this performance domain, the interface should be intuitive and not require the performers to be specially trained or have to acquire specialist knowledge to operate. The information that the device requires to operate must, therefore, be limited to information that would normally be supplied to a human drummer by the singer. The system must also possess the ability to respond by generating a suitable piece of music matching the requested parameters of comparable quality and complexity to that of a human.

The functional aspect of the interface described in this work, is focussed on the rehearsal sessions before the actual concert performance, since this is the period when the routine is developed and finalised. This is also the time during which there is detailed information exchange between the singer and the drummer. While the interface will allow the user to save performances for use in the concert, the area of interest is the usability of the interface during the training session where the performances are generated and modified. A user centred design approach has been adopted as described in [10] whereby musicians were interviewed to determine the required functionality of the interface and are involved in the testing and design through the use of formative evaluations

II. EVOLUTION OF THE ROBOTIC TABLA PLAYER

Thumru is the name given to a robot that was designed to play the tabla. The rationale for the robot was to provide realistic sounds from the tabla using bio-mimicking actions, with the eventual goal being the integration of the robot into a live musical band.

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The concept was first tested using a simple prototype shown in Fig. 1 with two three-fingered hands allowing the production of a basic rhythm on the table [11]. The prototype was controlled by a PLC to allow for faster development. The data for programming the rhythms was obtained by analysing tabla recordings and manually transcribing timing and stroke information. This simple prototype was, however able to show that robotic production of tabla rhythms was viable and was worth pursuing.

Fig. 1 Initial Prototype of Thumru

The next stage of testing was to have the robot perform alongside a human tabla player. The programming was modified so that it was now based on the theoretical framework for tabla music, as described in the next section of the paper. A drummer was asked to play alongside the robot as shown in Fig. 2. The performance consisted of both the robot and the human playing the same piece which consisted of a rhythm which was played at two different speeds. A video of the performance was featured at a session of the 2009 Commonwealth Business Forum as part of the 21st Commonwealth Heads of Government Meeting held at Port of Spain, Trinidad. This established the effectiveness of the robot as a credible alternative to a human drummer.

Fig. 2 Thumru playing alongside a human drummer

The use of the robot as a teaching tool was also explored as described in [12]. The concept was based on the visual cues which would be provided by the fingers of the robot. It presented a way for students learning to play the tabla to match the sounds to a finer stroke, thus allowing the robot to be a learning companion.

The first step towards integration with a live band was accomplished by using Thumru as a drummer, as shown in Fig. 3, with a small musical group consisting of a lead singer, a chorus, a harmonium, electronic tanpura and a mangeera. The performance was part of the launch of the Caribbean Invention and Innovation Centre and may be viewed at http://www.youtube.com/watch?v=ONOWUphdeck. The physical appearance of the robot was modified to endow it with a more anthropometric look so that it would be more appealing to the audience and the others musicians would be more comfortable performing with it. The robot was programmed to play a piece which included variations and cadential pieces which matched what was being sung.

Fig. 3 Thumru being used for a live performance

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Another test performance was also conducted with a singer in a concert environment as part of TEDx Port of Spain. As shown in Fig. 4, the robot was the only form of accompaniment for the singer. The video of the performance may be seen at http://www.youtube.com/watch?v=1gu19WwDYBU. In this performance the robot was under more scrutiny as it was a theatre environment and there were no other sounds to hide what was being played. These performances established the feasibility of including the robot with live musicians.

Fig. 4 Thumru used to accompany a solo singer

The next stage of integration would be to use the robot for multiple pieces and to establish some form of collaboration with the musicians of the band. What is necessary is the establishment of a mechanism with which the members of the band can communicate with the robot to create musical performances. Such an interface, between a robotic drummer and human musicians, is described in this work.

III. TABLA ACCOMPANIMENT

Traditional North Indian music is monophonic in nature. This means that all members of the musical orchestra try to intertwine to reflect the desired mood and tempo of the piece. An example of this might be when the singer has more lyrics to fit into a specific part of the performance, the accompaniment also increases apparent speed by adding filler beats although maintaining a fixed time sequence in the music [13]. The effect of this on tabla accompaniment is that while there is a framework within which the drummer must operate, there will often be the need to vary from the standard beat to suit the piece being sung, since no two songs would be the same.

The framework that guides the drummer is called the taal or rhythm and it has a fixed structure. This structure is shown in Fig. 5. It shows how a taal is divided into matras. These matras can be considered time periods that are used to measure the taal. The first sequence is the basic form or theka of Kaherwa taal. It can be seen that there are 8 matras. The number of matras remains constant during a performance regardless of the variations used. The X and O shown indicate the sam and khali respectively. The sam indicates the start of the sequence and usually coincides with the first beat of the cycle. The khali signifies the start of the unstressed beats in the cycle. This creates a type of symmetry in the sound between stressed and unstressed notes for each cycle. Each matra may be filled with bols, which are the notes of the tabla. The bols may be changed to create the variations required to match the mood of the performance and to better suit the meter of the song. There is also the example in Sequence 3 where multiple bols may be used in one matra which gives the feel of a faster speed while adhering to the structure.

Matra #	1	2	3	4	5	6	7	8
Sequence 1	Dha	Ge	Na	Ti	Na	Ke	Dhin	Na
	X				0			
Sequence 2	Dha	Te	Dha	Ge	Tun	Na	Ke	Na
	X				0			
Sequence 3	Dha	Dhin	Na Na	Dhin	Na	Tun	Na Na	Te Te
	X				0			

Fig. 5 Variations in Kaherwa taal

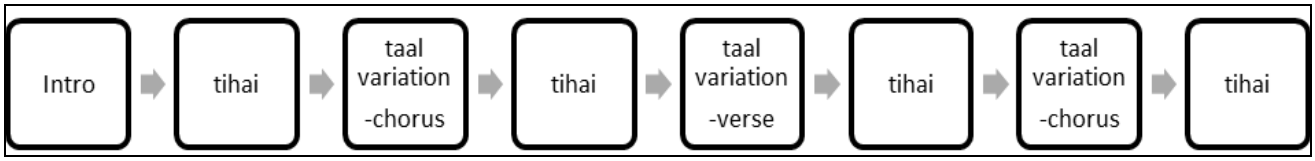

Fig. 6 The basic tabla accompaniment structure for a bhajan

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In addition to the cyclical structure of tabla accompaniment discussed thus far, there also exist cadential pieces that will be played within performances. These pieces are not meant to be repeated throughout but rather to act as markers to signify some change in the song [14]. The most common example of a cadential piece is called a tihai. It is essentially a short piece that when repeated three times, its last note would coincide with the first note of the taal being played as shown in Fig. 7.

taal	Dha	Ge	Na	Ti	Na	Ke	Dhin	Na
taal	Dha	Ge	Na	Ti	Na	Ke	Dhin	Na
tihai	TiRa	KeTe	Dha	Tira	KeTe	Dha	TiRa	KeTe
taal	Dha	Ge	Na	Ti	Na	Ke	Dhin	Na
taal	Dha	Ge	Na	Ti	Na	Ke	Dhin	Na

Fig. 7 Insertion of a tihai in a taal sequence

The typical song that would be performed by a traditional North Indian religious music group is called a bhajan, for which the accompaniment on the tabla follows a pattern which is shown in Fig. 6. Usually there is a short musical introduction by either the singer or the instruments to before the start of the bhajan itself. Once the bhajan has begun, there is usually a verse which may be repeated followed by a chorus and then perhaps a musical interlude. The lengths of each of these parts remain the same throughout the bhajan and are all often of the same duration. The tabla accompaniment may be different for the chorus and the verse and different tihai's may be used for the transitions shown in Fig. 6.

IV. REQUIREMENTS ANALYSIS

The robot is expected to interact with musical performers; specifically singers in a manner which is comfortable to them. It is also expected that the amount of information that the user is required to input would be similar to what would normally be communicated to a tabla player during the rehearsal period or during training. To determine the functional requirements of the interface, interviews were conducted with several tabla players. Drummers were asked what they were required to do and what information is usually provided for them.

The tabla players interviewed indicated that there is often collaboration before a piece is sung, where the singer gives some direction to the drummer. This discussion is mostly based on parameters that were decided during a previous training session. During the training, there are often more specifics available to the drummer. The main items of importance are as follows:

- Speed

The general speed is usually stated by the singer before the song begins. The drummer will often have to make a slight adjustment to the speed as the bhajan is being sung however, to match the singer.

- Taal

This is sometimes specified by the singer since some singers have preferences for a specific taal for the piece that they are singing. The majority of the time however, the taal is determined by the bhajan that will be sung. The variations on the basic taal that will be played are based on the bhajan, the speed and the mood of the song being sung. During rehearsal the singer will indicate agreement or not with the variations that the drummer is playing and may ask for some changes.

- Mood

The mood is sometimes stated expressly by the singer when they indicate that the bhajan will be sung in a certain raag. The raag refers to the melody of the music and is linked to the emotion of the music. At other times the bhajan itself is enough to cue the drummer into the emotion since the lyrics could only invoke one type of mood. In training, the singer may further specify how the drummer should convey the mood, e.g. using a lot of cadential pieces for upbeat bhajans and a standard taal for more solemn songs.

- Bhajan

As stated before the bhajan specifies to the drummer the taal that will be used, gives an indication as to which variation should be used and also the mood of the piece. The bhajan will also give an indication about how long the verses are and the chorus length, thus telling the drummer where to insert a cadential piece like a tihai. There will be variations specific to each music group however, since the number of rounds of taal for each verse would depend on how many times lines are repeated, etc. The singer would usually specify this during training as well as the number of verses that will be sung.

Analysing the information provided, it can be seen that the following pieces of information are usually provided by the singer during training:

- Speed
- Mood
- Structure of the accompaniment

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- Which taal
- How many rounds/verse
- How many verses

- If the piece played by the drummer is acceptable or not.

The drummer will generally have to use the supplied information to generate accompaniment to match the request of the singer complete with cadential pieces. The created pieces will also need to be stored for later use in a performance.

V. SOFTWARE DESIGN

The goal of the design was to create an interface that would be able to be used by singer easily without much additional training to create tabla accompaniment pieces of the complexity necessary to simulate a human drummer. It would be used in training sessions beforehand to finalise concert pieces. The software would need to facilitate three main functions; allow the user to create new performances without having the specialist knowledge of a tabla player, allow the user to edit performances until the desired accompaniment is achieved and allow the user to save and recall performances that would be later used. The design of the software is illustrated in Fig. 8. The three main functions are the creation of a new performance, the ability to recall the last performance and the ability to recall any previously save performances.

The new performance creation is designed to guide the user through a series of sequential steps that are required for the generation of the performance. The user is first asked to select the required taal, followed by the mood of the piece. The software then uses these two values to assign a taal selection factor. This factor is then taken to the Taal Resources directory. The directory contains pre-programmed variations for all of the taals available in the software. Each of the variations is stored with a taal selection factor which is based on the mood and taal. Each variation will also have a suitability factor which be discussed shortly. All of the variations with a matching taal selection factor to the user generated factor will be added to a selection list, from which a variation would be randomly chosen. A similar list of tihai's with matching selection factors will also be generated, from which one will be chosen. The user would then be prompted for information regarding the structure of the performance, such as; the number of introductory rounds to be played, the number of rounds required per cycle, the number of cycles and the speed. All of these values would be stored in the performance parameters directory.

The performance is then played so that the user can determine the suitability of the parameters. Once a performance has been completed, the parameters are immediately stored in the saved data directory as the last parameters.

As the user continues to practice and perform with the robot, the software must become better at anticipating which variation of the basic rhythm the user will prefer, just as a human drummer that practices regularly with a singer would be better able to anticipate what the singer would want. In order to accomplish this, a form of learning must be implemented in the software. The user will be able to train the software by providing feedback on the suitability of each new performance by either giving the performance a positive or negative review. If the review is negative the performance is discarded and the suitability factor of the variation is reduced by 1, down to a lower limit of 1 i.e. no variation will have a suitability factor less than 1. The user is then prompted to start the process over. If the review is positive, the suitability factor of the selection is incremented by 1, up to a value of 10, i.e. no variation will have a suitability factor greater than 10.

This suitability rating will be used when matching variations to the selection factor. Each time the same selection factor comes up all matching variations of the basic rhythm will be used to populate the selection list as stated previously. The number of times that the variation appears on the list however, is determined by the suitability factor. Thus if 5 variations with a suitability factor of 1 exist for a particular selection factor, the list generated will only have 5 entries. Whereas if one of these variations has a suitability factor of 3, the list will have 7 entries, with the variation having the suitability factor of 3, appearing three times, thus making it more likely to be selected randomly. The user will now be given the option to save the performance. The performance may be saved as any of the pre-sets in the software. Saving the performance will result in the parameters being stored in the saved data directory.

The last performance menu allows the user to load the parameters of the last piece that was played. If selected, it pulls up the last performance parameters from the saved data directory and gives the user two options. The performance may be played again, in case the user wants to review the piece before taking further action or the structure may be edited. Editing does not allow the user to change the variation or the tihai's only the structure of the performance. After editing the user is presented with the option to store the piece similarly to the creation of the new performance. The user will not be asked to rate the system again, since it is assumed that it would have already been rated.

The saved performance menu allows the user to pull up any of the saved pre-sets. Once a pre-set is selected the parameters are retrieved from the saved data directory and moved to the performance parameters directory and selection performed. When the selection has finished playing, the user is taken back to the main menu.

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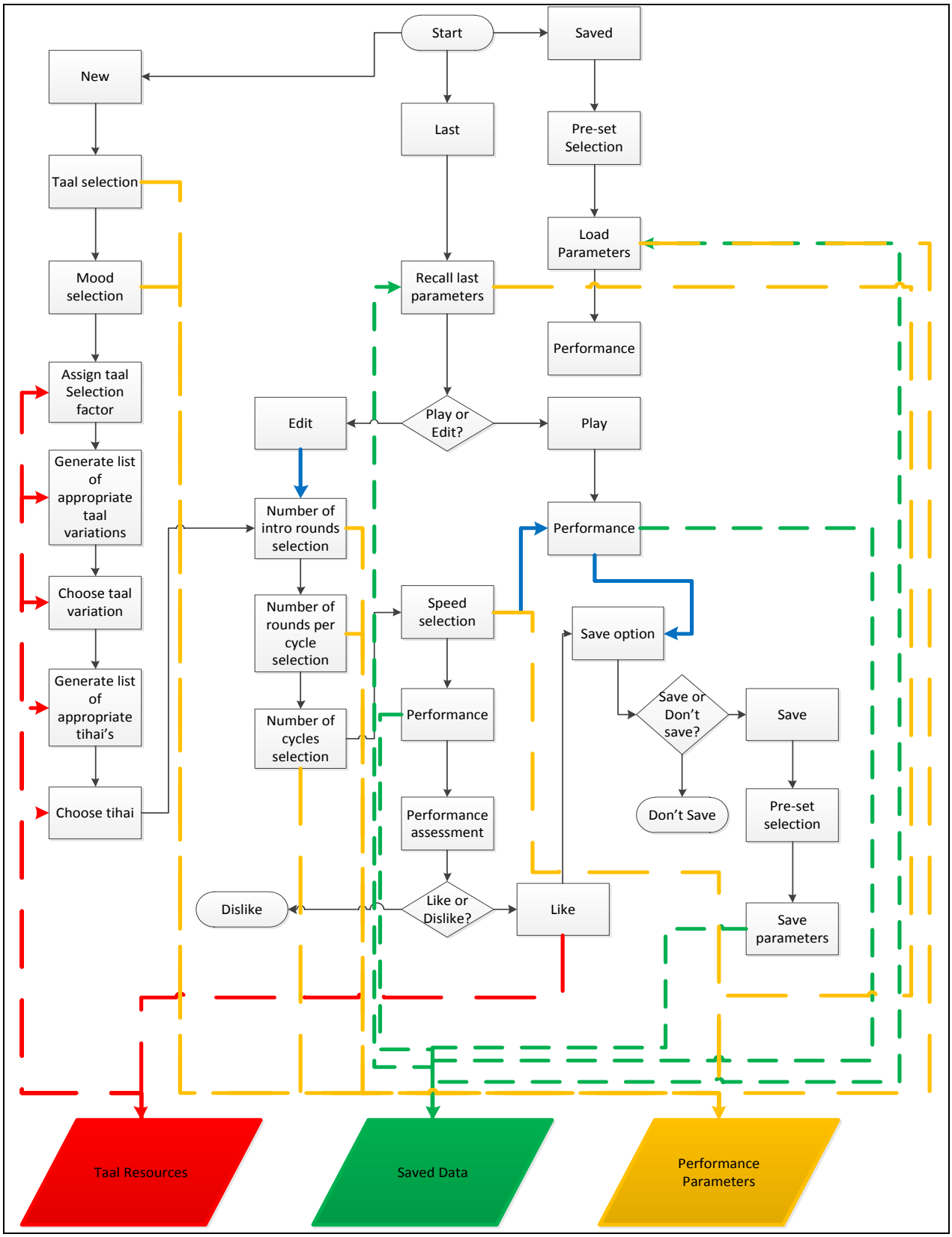

Fig. 8 Robot Algorithm

VI. INTERACTION DESIGN

In her work on Human-Robot Interaction, Sholtz identified five roles that humans may take when interacting with robots [4]. They included supervisors, operators, mechanics, peers and bystanders. In this instance, the role that most people interacting with the robot will fit is the peer role. A peer interaction is one where the users are able to give instructions within

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the designed framework of operation but are unable to change the framework itself. The typical user for the device will be the singer in a musical group. The framework within which the robot operates is to create and play accompaniment; so while the user will interact to provide information that will lead to the creation or performance of tabla accompaniment, the user will not be able to make the robot into a solo tabla performer or make any other fundamental changes to the way the robot operates.

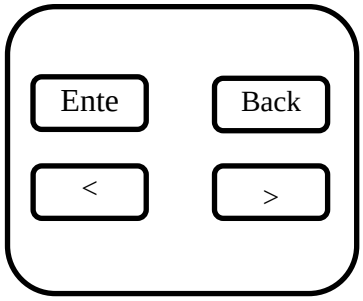

Fig. 9 User Interface Device

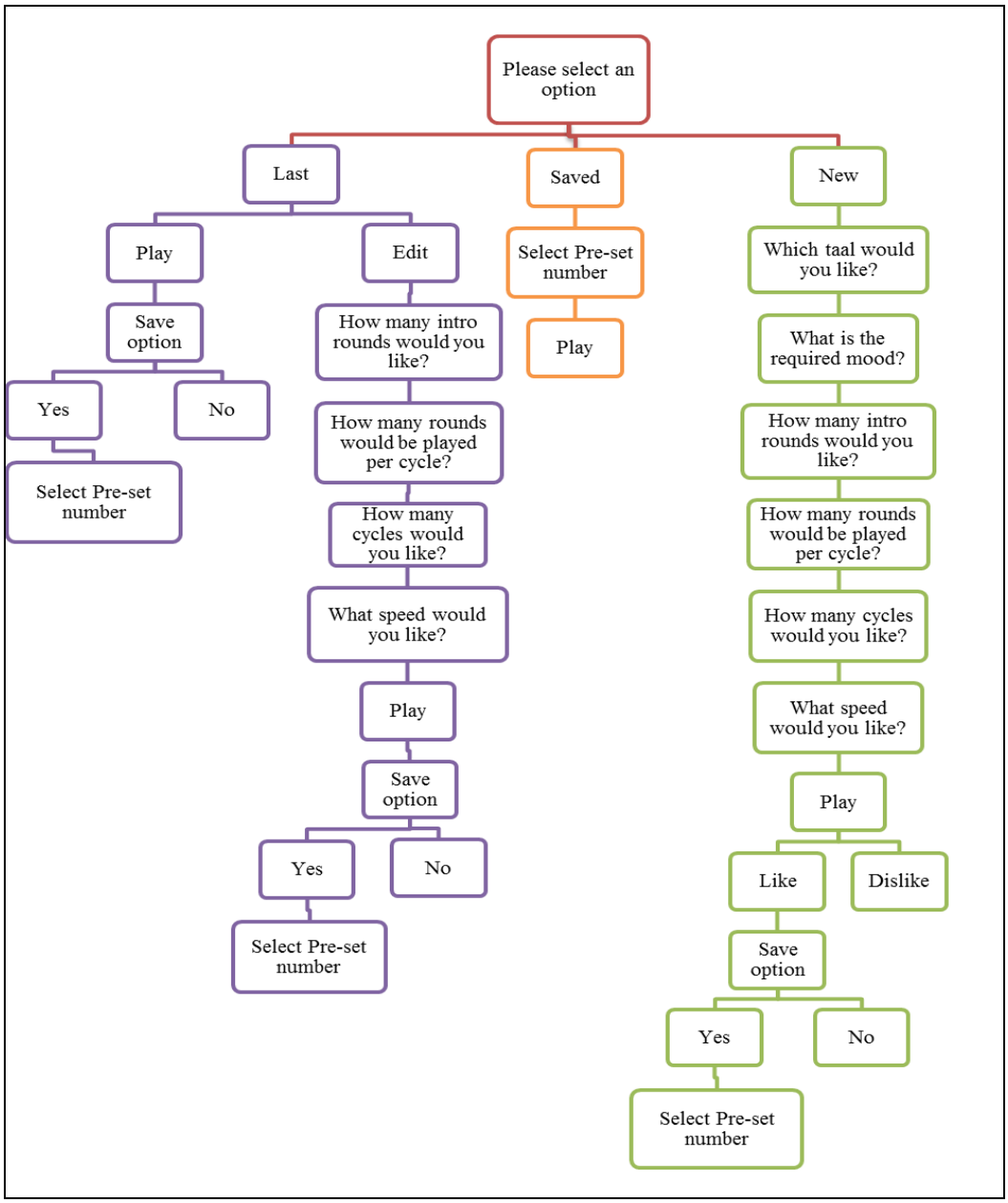

Fig. 10 User Menu Map

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Since this form of interaction relies heavily on information being readily shared between the robot and the human, the menu design must allow for the robot to receive all of the information required to perform its tasks. Conversely, during the interaction, the user must experience full awareness of the robot's status. The user will need to be clearly informed about which parameters have been accepted and what options are available. The user must also be able to judge from the output of the robot, which in this case is the performance piece, if the desired actions are being undertaken and if not, must be allowed to make corrective changes.

The robot is controlled by an Arduino Uno microcontroller. The interface was also coded on the device so that the menus would be displayed on the serial monitor of an attached computer. The menu is therefore displayed through a monochrome text interface. Menu navigation was achieved by the use of a simple keypad as shown in Fig. 9. The arrow buttons, <and> allowed the user to scroll through the options in each menu until the user arrived on the desired selection. The selection would then be confirmed by pressing the enter key. Once the enter button was pressed, the user would then be taken to the next set of options or if all sub-menus were completed would bring the user back to the main menu. The back button allowed the user to return to the previous menu or cancel an operation. It would be used if a previous parameter had to be changed either due to an error or a change in desired output. It also allowed the user to escape a menu if it was mistakenly selected. The menu map shown in Fig. 10 represents the navigation path that will be available to users. At each level of the menu, there are multiple possible selections. The main menu would present the user with the three main functions discussed in the software design: creation of a new performance, loading the last performance and loading one of the saved pre-sets.

It is intended that the user creates the new performances during training sessions before a concert takes place. The last performance option would be used for immediate review and for edits to be done. Once the desired performance is created, it will be stored as a pre-set and will be available to be immediately called up during the concert.

VII. FORMATIVE EVALUATIONS

Preliminary testing was conducted on the interface design to get feedback on the current system design. As described in [15] formative evaluations are generally used to collect information for further design refinement. User based testing was done to obtain inputs about the viability of the design. The user group consisted of persons who were all familiar with North Indian music but possessed varying degrees of musical capability. The users were given a standard 5 minute training session on the functionality of the interface and navigation methods. During the training session, the users were shown the three major sub-menus, with an explanation about the function of each. The use of the navigation keypad was demonstrated and the function of each button was explained. The users were then given a walkthrough of the process for creating a new performance, following which, they were shown how to save, edit and load saved performances. Users were then allowed 2 minutes to practice navigating the menus with the aid of the trainer.

After receiving the training, they were asked to perform eight tasks shown in Fig. 11 while being observed. After the tasks were completed a post evaluation interview was conducted to further identify problem areas.

Task 1:
Create a new performance with the following features
Kaherwa taal
2 intro rounds
4 rounds/cycle
2 cycles
Fast speed
Like the performance
Save the performance to Preset 2

Task 2:
Create a new performance with the following features
Bhajan Theka
4 intro rounds
4 rounds/cycle
1 cycle
Medium speed
Like the performance
Don't save it

Task 3:
Create a new performance
Save the performance in Preset 3

Task 4:
Load the saved performance in Preset 2

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Task 5:
Load the last performance
Edit the last performance to add the following parameters
1 intro round
2 rounds/cycle
2 cycles
Fast speed
Save the performance to Preset 1

Task 6:
Load the last performance and play it

Task 7:
Create a performance to accompany you while you sing two verses of a song
Save this performance

Task 8:
Load this performance and perform the bhajan

Fig. 11 User evaluation tasks

All of the subjects were able to accomplish the tasks given within a 20 minute timeframe. Each was able to navigate the menus with some degree of comfort and they did not encounter problems in designing an accompaniment piece. Some problems were encountered where the subject had accidentally gone into the wrong menu and had forgotten how to correct their mistake. Otherwise all of the users agreed that the functionality was there for a person to create a tabla accompaniment.

During the interviews that followed, most of the subjects complained that the menus lacked contrast and there was no distinction between the menus that they were navigating. The text interface was identified as being cumbersome and required too much reading. All participants indicated that they would have preferred some type of graphical interface with contrasting colours. A few functional changes were also requested; users requested the ability to select separately how many cycles are played for both the verse and the chorus, when to insert tihai's and also the ability to rename the pre-sets. Overall, however, the users reported that they found the system to be adequate for what it was designed

From the study it was noted that a few areas needed to be addressed; menu navigation, clarity and functionality. For the next iteration of the design therefore, a graphical user interface coupled with a touchscreen interface will be developed. This combination will allow more information to be displayed at one time, providing better understanding of the menu sequence and hierarchy and also creating a more intuitive interaction interface by permitting the user to select the menus or options they desire by simply touching where they are on the screen rather than having to scroll through text based menus. The use of pop-down or pop-out menus for selecting parameters will show users clearly the options available to them and will let them change their selection easier. Graphical cues such as symbols and colours will be added to aid users in remembering where they can go to accomplish tasks and the navigation options that are available. The added functionality requested will also be included to give more freedom when designing a performance. These changes should lead to a faster, more efficient and user friendly interface.

VIII. CONCLUSIONS

The interaction system presented has shown that it has the capability to allow singers to generate a tabla accompaniment without any specialist knowledge of programming or tabla playing. The interface was simple enough for novice users to navigate by themselves after only a short period and users were able to successfully able to perform at least one musical item while being accompanied by a tabla performance that they designed for themselves. The testing also pointed out a few additional areas that need to be improved to better user satisfaction. This work represents a good basis for the development of an interaction system for the generation of tabla accompaniment in traditional North Indian religious music.

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