Non-choreographed Robot Dance

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Abstract

This paper describes an attempt of teaching the Nao robot to dance on music. This research has tried to move away from the current choreographed approaches to Nao dance, and investigate how to make the robot dance in a non-predefined fashion. Aspects of both music and dance are investigated, and descriptions of how such elements were implemented in practice are presented. Moreover, focus has been put not only on the analysis of music's beat in order to build a dance, but other elements of music as well. The paper concludes by describing aspects that still need to be tackled in the future before the Nao can truly perform a non-choreographed dance.

1 Introduction

This research aims at investigating the difficulties of enabling the humanoid robot Nao to dance on music. The focus is on creating a dance that is not predefined by the researcher, but which emerges from the music played to the robot. Such an undertaking cannot be fully tackled in a small-scale project. Nevertheless, rather than focusing on a subtask of the topic, this research tries to maintain a holistic view on the subject, and tries to provide a framework based on which work in this area can be continued in the future.

The need for this research comes from the fact that current approaches to robot dance in general, and Nao dance in particular, focus on predefined dances built by the researcher. The main goal of this project is to move away from the current choreographed approaches to Nao dance, and investigate how to make the robot dance in a non-predefined fashion. Moreover, given the fact that previous research has focused mainly on the analysis of musical beat, a secondary goal of this project is to focus not only on the beat, but other elements of music as well, in order to create the dance.

The paper starts by shortly describing the Nao robot. Then, a view on robot dance is presented, in which the robot moves in a choreographed manner, predefined by the researcher. The paper then continues by analyzing how should a non-choreographed dance be built into the Nao, and provides descriptions of some of the essential aspects that need to be considered in the development of such a dance. To achieve that, elements of music are first described, then analyzed, and later transformed into dance. The paper concludes by presenting aspects that still need to be tackled in the future, before the Nao can perform a truly non-choreographed dance.

This research has also resulted in practical implementations of both a choreographed, and a non-choreographed dance for the Nao robot. Although these implementations are minimal in some regards, they provide proofs of concepts for the ideas discussed here. Elements of this practical undertaking are described throughout the entire paper.

2 The Nao Robot

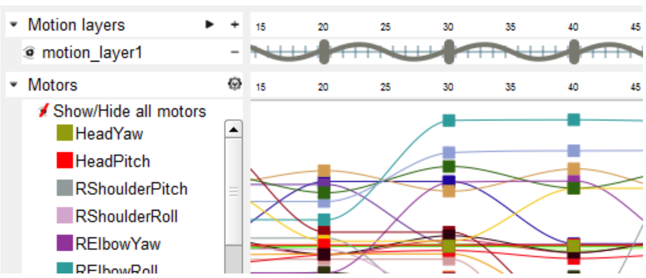
The Nao Robot is a small-sized humanoid robot capable of complex physical movements and pre-built with numerous capabilities essential for the development of behaviors that mimic humans. Given its physical capabilities, i.e. 25 degrees of freedom that allow complex movements, inertial sensor for stability, ultrasound captors for positioning in space, and others more, it is easy to understand why the Nao has become the standard for the Robot Soccer World Cup (Robocup). Initiatives such as the Robocup competition are ideal playgrounds for various Artificial Intelligence tasks that researchers in the field envision as one day being mastered by humanoid robots: such as learning, decision making, planning, etc.

Given its fast acceptance in the soccer competition, the Nao robot is usually associated with its football persona. However, its humanoid abilities open the gates to its use in research in other aspects of human behavior, such as emotional intelligence. This research focuses on dance, a topic that has not yet been fully explored in the context of humanoid robots. Two dances have been developed here for the Nao, in an attempt to explore its capabilities and appeal beyond football playing.

3 Choreographed Dance

The first phase of this project was the generation of a choreographed dance for the Nao robot. In such a dance, the motion of the robot is predefined for the provided musical piece. In specific circumstances, dance choreography can also allow for improvisation on the part of the performer; however, this paper will refer to choreography in a strict sense, as the creation of spatiotemporal sets of postures and movements stored programmatically in the robot and performed in a predefined sequence at a later stage. In this view, "the purpose is not to develop a creative machine but rather a machine to be used as an expression of creativity" of the artist or scientist [1, p. 4].

A basic choreography for the Nao has been built in this project using the timeline functions of the Choregraphe software offered by Aldebaran Robotics (the builders of the Nao robot). Each movement can be achieved by physically moving the joints of the robot and then saving the motor positions inside a frame of the motion layer, for later use.



Screenshot depicting a part of the graphical user interface of the Choregraphe software, allowing the storing of positions in the timeline.

The musical piece of choice for this choreographed dance was 'La Macarena', by the Spanish music duo 'Los del Rio'. The choreography was inspired by the original Macarena moves, one of the most recognizable choreographies of modern times. In public displays of the robot, the dance proved to be very popular with the audience. This confirmed the idea that a robot dance can be accepted as an artistic representation, even if performed by a creativity-free robot, used as a mean of expressing the creativity of the choreographer.

Such choreographed dances have been repeatedly created for the Nao, and are shared by people around the world on video sharing websites [24, 26, 25]. Even the Robocup competition has introduced a Dance challenge in its program [21] (only at the junior level, and focusing more on the creativity of the team, than the creativity of the robot itself). However, this research tries to move away from the choreographed approach to robot dance, and investigate aspects needed for the generation of a non-choreographed dance on the robot.

4 Non-choreographed Dance

The main goal of this research is to investigate aspects that need to be considered in the development of a non-choreographed dance for the Nao robot, in the sense of a dance that is not predefined by the developer, but which is built by the robot based on the music it hears. In this project, a basic non-predefined dance has also been built for the Nao, using the Python programming language and integrated with the other behaviors using the Choregraphe software.

Since the aim here is to look at dance not as a predefined movement, but as something that emerges from music, we will first, in subsection 4.1, look at what music is, and what are the essential characteristics relevant to dance. The most important characteristic of music from the perspective of dance, the beat, will be discussed in detail. This is also the characteristic most studied in mathematical and computer aided music analysis. The paper however, will also introduce another element of music, the meter. Analyzing the meter complements basic beat analysis and gives even more expressive power to the robot dance.

Subsection 4.2 will present different approaches to music analysis, and will also describe the methodology used in this research to analyze the musical sample. Only then will we discuss, in subsection 4.3, how these elements are transformed into a non-predefined dance. Finally, subsection 4.4 'Looking into the Future' describes topics that have been studied in this project but have not yet been put into practice.

4.1 Music

Dance is a physical expression of music and, in order to understand dance, we must first understand music. Music is an art form created by the generation of sounds, and some scholars consider musical expression an innate human ability, which emerges earlier than any other human talents [20]. There exists no commonly accepted description for this subjectively perceived art form, as definitions of music are based on social context and culture, and are disputed between musicians, composers, music critics, philosophers, sociologists, and many others. However, a general definition is that of Roger Sessions, who saw music as controlled movements of sound in time [6].

Elements of Music

By taking into account the definition presented above, the elements of music can be divided into two main categories: the ones that relate more to the sound aspect of music, such as the melody, texture, harmony, tonality, and instrumental combinations; and the ones that relate more to the temporal aspect of music, such as the beat. Therefore, musical intelligence implies both sensitivity to sound and responsiveness to sequences of sound [22].

The sound elements give a lot of music's expressive power, and in dance they might dictate the vigor, or the kind of moves that are appropriate. However, this research has focused more on the temporal elements of music. These elements are essential to the development of a synchronized dance, and their implementation will bring the biggest contribution in the creation of a dance that looks and feels as being a match with the music.

Beat

The beat is probably the most important temporal element of music, as it defines the basic time unit of the piece. In dance, it marks the time intervals between which movements are being performed. An important note here is the fact that although dance is performed on the beat, it is not necessarily performed on every beat. A dancer can for example dance on every second beat if the musical beat is too fast. Therefore, the danceable beat, the smallest time division on which a dancer can comfortably move his body, can differ from the beat of the music, but it is always a function of it.

In this research, the 'Habanera' aria from the 'Carmen' opera by Georges Bizet has been chosen for the non-choreographed dance of the Nao. Although performed at different speeds by different orchestras, the specific version chosen here has a beats per minute (BPM) count of approximately 135. As this was deemed too fast for the robot, its dance was performed at approximately 68 danceable beats per minute, without any loss of expressivity in the resulting performance.

Meter

Another aspect essential to dance is the organization of music into reoccurring structures of accented and normal beats. This grouping of beats, called meter, dictates the grouping of the movements that are to be performed in dance. In many cases, it does not only dictate the number of steps that are performed in a group of movements, but also the type of music and therefore of dance moves that are appropriate. A waltz for example is performed on a triple meter piece [4], and therefore the steps are grouped together in threes. Here, as well, it should be noted that although the meter dictates the grouping of movements, it does not necessarily equate it. A dancer can usually dance without worries on a different meter than the meter of the music, as long as the two meters are a multiple of each other.

In this project, the musical fragment chosen from 'Carmen' was identified by the algorithm used, and described later, as a quadruple meter (groupings of 4 beats), and was transformed to a duple meter (groupings of 2 beats) by the transition from actual beats to danceable beats. The dance performed however, was still on a quadruple meter, not a duple meter; just as a duple meter dance could also be performed on a quadruple meter music. However, dancing in triple meter on a duple meter music for example, would look odd even to an inexperienced dancer.

4.2 Music Analysis

There are numerous approaches to extracting the temporal characteristics from music. However, each of them have a different set of disadvantages, and many are not applicable for a robot dance [14]. Moreover, they usually focus on the detection of the beat, without also looking at the meter or other elements. The following part describes different methods that have been used in previous research. This subsection will then continue by describing the derived method that was put into practice for this project, in order to extract both the beat and the meter.

Previous Research

One of the most famous implementations of beat tracking systems is that developed by Goto [11, 12]. His approach was to analyze the music in real-time, employing a multi-agent structure, in which each agent predicts the interval between beats, and the timing of the next beat, using different parameters. Yoshii et al. [23] have taken this approach of Goto, and implemented it successfully on the ASIMO robot (another humanoid robot, developed by Honda), enabling it to synchronize its steps with musical beats in real time.

The above approach however, relies on a roughly constant tempo. A response to this shortcoming is the approach by Nakahara et al. [14]. They propose an implementation based on beat intervals and the integration value of decibels, which can track tempo changes in audio signals, by continuously transforming the audio signals into spectrograms with the help of Fast Fourier transforms.

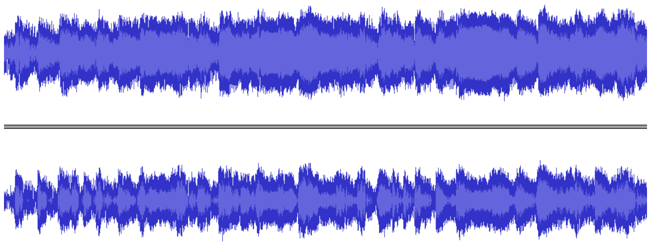
Although the music for the Nao dance that was developed in the current research was analyzed offline, consideration has been put into what could be feasibly achieved on the robot itself in real-time. Both previously mentioned approaches were deemed as being too resource-intensive for the computational power of the small sized Nao robot. The Nakahara et al. implementation, for example, was performed on a cluster of 2GHz dual processor machines.

A frequently cited paper on fast beat detection of polyphonic (real world) music, is that of Scheirer [19]. His implementation is fast and can detect beats in almost real time. The approach is that of dividing the sound into six different frequency bands, constructed from a number of low-pass, band-pass and high-pass filters. Each frequency's envelope (smoothed representation of the positive values of the waveform) is calculated, and their differentials are computed. Each differential is then passed through a bank of comb filters, out of which one will phase lock with the signal, determining the beats per minute (BPM) value. This approach has a demonstrated accuracy and was repeatedly implemented, as it can handle a wide range of music genres. It is however often described as very complex and time consuming to implement.

A simpler approach to beat analysis is that proposed by Arentz [2]. Starting from the assumption that the beat is given by the drum instruments in most songs, he first filters out the samples with the lowest amplitudes, keeping just the 5% highest amplitude sounds. The remaining peaks can then be treated as rough approximations of the beats in the music. To determine the BPM, the filtered music is compared with all possible BPM values within a range, and the number of times a peak falls exactly on the beat is counted and stored in a table, in terms of the number of samples between each beat. Once the comparison has been performed with all BPM values in the range, the entry with the highest match count is assumed to be the correct one, and a BPM value is computed. This is a simple, but fairly accurate approach.

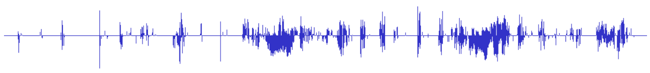
Beat Detection

The current research attempts to provide a general framework for investigating the topic of robot dance, and incorporate more than just beat analysis in order to build a dance for the Nao. For this reason, a very basic implementation has been used for beat detection, largely based on the method proposed by Arentz.



The waveform of the musical sample extracted from the 'Habanera' aria from the 'Carmen' opera by Georges Bizet.

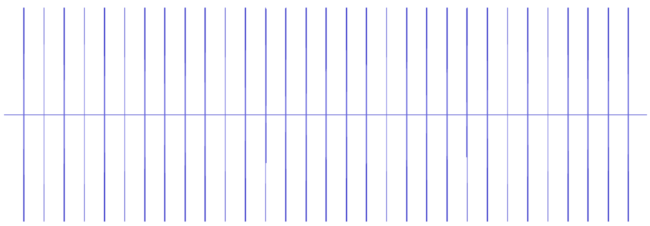
First, the left and right channels of the music piece have been combined together to create a mono-channel music file. Then, assuming that the beat will be given by the drum instruments, the music piece is filtered to keep only the samples with highest amplitude. This can be referred to as a high-pass filter, where the cutoff frequency is computed such that 95% of the samples are eliminated.



Waveform after joining the two channels and removing the sounds with low amplitude.

Next, the remaining samples are tested against a range of predefined beats per minute values, starting at increasing offsets from the start of the music. The BPM value whose beats fall most often exactly on time with a non-zero amplitude of the filtered music is taken as the BPM. Although this process involves a big number of computations, the algorithm has a very low complexity, being therefore not very computationally expensive.

The musical segment from 'Habanera' has been detected by this process as having a BPM value of 135.



Click track depicting the 135 BPM value extracted from the above filtered music.

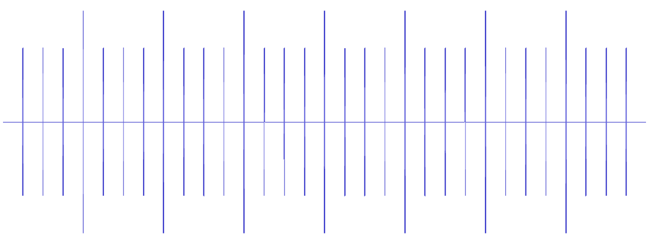
Meter Detection

To detect the meter of the music, inspiration has been found in the often used concept of self-similarity in the available literature. Self-similarity has been previously used for beat detection (for example by Foote and Uchihashi [8]), but has also been suggested as being valuable in detecting the structure of music (for example by Dannenberg [7] or Foote [9]). Self-similarity can therefore be used to detect the meter as well.

The meter is usually marked by an accented beat, followed by a number of not accented beats. This is achieved by an increased sound amplitude on the accented beat. A music piece would therefore contain reoccurring structures of accented and normal beats, marking the meter.

To detect these reoccurring structures, a comb filter has been used, where the filtered signal has been added with a delayed version of itself. The comb filter has been applied first with a delay value equal to twice the distance between two beats of the computed BPM (to test for a duple meter), then with three times the distance (to test for a triple meter), etc. The meter for which the filter caused the most constructive interference was chosen as the meter of the musical piece.

The musical segment from 'Habanera' has been detected by this process as having a quadruple meter.



Click track at 135 BPM, emphasizing a quadruple meter.

4.3 Dance

Dance is the physical expression of music. It was a fundamental mean of communication throughout human history [17]; and some of its underlying features, are at the core of social dynamics, being therefore a prerequisite for comfortable robot to human interaction [13]. Ideally, although dance is built from previously learned movements and routines, a true dance should not be predefined, it should emerge from music. This research has focused on some essential temporal elements of music, beat and meter. Following is an account of how these elements were transformed into a non-choreographed dance for the Nao.

Dance Moves

Previous research regarding robot dance has mainly focused on the aspect of beat detection, while this research claimed that in order to build a true dance, the meter should be closely analyzed as well. As described earlier, the meter gives the grouping of beats in the music, and therefore dictates the grouping of movements in dance. Usually, dances can also be performed on different meters, if the value of the music meter and the value of the danced meter are a multiple of each other. As an example, a quadruple meter music can be danced as a duple meter music by a slow dancer, while a duple meter piece can be danced as a quadruple meter by combining two meters together. However, dancing in duple meter on a triple meter music, would look odd even to an inexperienced dancer.

To ensure that the Nao robot does not dance only on the beat, but more importantly on the meter, dance moves have been programmatically encoded in the robot not as individual movements, but as groups of movements. For each meter value a specific set of movement groupings apply: a duple meter music would be danced with routines formed of two movements, a triple meter music would be danced with routines formed of three movements, etc. Focus has been put in this research predominantly on the encoding of groupings relevant to a quadruple meter, because of the chosen melody. These groupings were achieved by saving the desired motor positions in arrays of four elements. However, further development of the software could expand this implementation with sets of movements for other meters, and the ability to choose the appropriate group based on the meter of the song.

```
#~ Head Left -> Right
self.moves.append([
    ["HeadPitch", [-0.00618, -0.00618, -0.00618, -0.00618]],
    ["HeadYaw", [0.61663, 0.00916, -0.62285, -0.01385]]
    ])

#~ Hands down
self.moves.append([
    ["LElbowRoll", [-1.02620, -1.02620, -1.10290, -1.02620]],
    ["LElbowYaw", [-1.38064, -1.38064, -0.56916, -1.38064]],
    ["LShoulderPitch", [1.39130, 1.39130, 1.59685, 1.39130]],
    ["LShoulderRoll", [0.35738, 0.35738, 0.66725, 0.35738]],
    ["RElbowRoll", [1.31161, 1.03703, 1.04163, 1.03703]],
    ["RElbowYaw", [0.52612, 1.38516, 1.37442, 1.38363]],
    ["RShoulderPitch", [1.70125, 1.42973, 1.45274, 1.42973]],
    ["RShoulderRoll", [-0.77778, -0.35746, -0.36667, -0.35746]]
    ])
```

Screenshot of part of the Python code, defining two of the movement combinations appropriate on a quadruple meter.

To make things easier, a default position has been first decided upon, from which the sets of movements start, and towards which they end. This way, successions can be stacked one after another to create a dance, without worrying about the transition from one set to the other.

Humanness of Movements

At the beginning of this project, the aim was to develop a smooth dance, which makes no breaks between moves. It was however visually observed that such a routine looks less like a dance on the chosen music, and more like a continuous random movement. Although not always consciously made in human dance, a dancer 'freezes' for a fraction of a second after each move. This break between the movements marks the beat, giving the dance synchronicity with the music.

In dance, motion phases and pause phases complement each other. Both motion and pause can be seen as gestures that build together the expressivity of the dance [5]. The amount of the pause after each motion depends on the type of music being danced. In some dances, the pauses can even be non-existent, so called legato movement. In dances which depend on the temporal elements of music however, they are very important, as the dance is continually broken by fractal pauses that coincide with the breaks in the music. In this way, pauses serve as punctuation marks [10].

Since the chosen melody for Nao's non-choreographed dance has strongly defined temporal elements, the need arose to mark these elements in his dance, similarly to a human dancer. This was achieved by transforming the quadruple meter routine from a set of four movements, to a set of eight phases (motion, pause, motion, pause, etc.). For ease of editing, the encoding of moves has been kept the same (i.e. arrays of four elements). However, to perform the small breaks, a function has been introduced that translates the set of encoded movements, to a succession of moves (taking 75% of the total movement time) followed by a pause (taking 25% of the total movement time). Counterintuitive at the beginning, these breaks mark the beat and make the dance look in sync with the music, and thus more human. The proportion of the two phases in regards to each other has been decided through observation, but further research is needed to decide how long should the robot pause in his dances.

Stand-by

On a side note, another behavior was built into the robot to make it appear more human, that has no strong connection with dance, but which supports it. In public displays of the Nao dance, it was expected that the robot will sit motionless for long periods of time before prompted to perform a dance. Therefore, a stand-by behavior was created, in which the robot performs one slight random movement every minute, such as moving his head or arm. From accounts of the audience, this behavior helped soften the motionless look of the robot and created an "it's alive" effect, giving therefore even more credibility to the dance routine.

4.4 Looking into the Future

The topic of non-choreographed robot dance encapsulates a multitude of issues, many of which could not be pursued in this current research. Following paragraphs describe some of the issues that were investigated for this project but were not put into practice due to time constrains.

Real-time Music Analysis

A main issue not implemented here is that of real-time detection of the characteristics of music. Different approaches have been analyzed, and the choice for offline analysis was made for practical reasons. However, a true dance will eventually need to form around a live stream of music.

Other Elements of Music

This research has focused only on time elements of music, and from them only on the most important two, beat and meter. An investigation of the sound elements of music as well, such as tonality, texture, melody, might bring further insight into the topic of robot dance. Although previous research in robot dance in particular did not yet go far from simple beat analysis, research in music signal analysis can be brought to life in a robot dance.

Berenzweig [3] for example provides a method for locating portions of music in which vocals are present. Such an analysis could aid the robot in performing some dance patterns on a vocal fragment of music, and other patterns on instrumental fragments; providing therefore even more expressivity to the dance.

Orife [18] takes an in-depth look at rhythm analysis. Moreover, he describes a process of dividing a complex melody performed by different instruments into individual steams for each instrument. Such an analysis could aid the decision of appropriateness of moves for different types of music (such as jazz or rock). Also, since dance is usually performed on the beat of only one of the instruments playing, isolating the instrument can bring further advantage in detecting the beat and the meter.

Foote [8, 9] introduces the beat spectrum, a measure of acoustic self-similarity used to visually identify structural and rhythmic characteristics of music. Dannenberg [7] also provides a method for structural analysis of music. Such approaches could be very beneficial to a robot dance, as they provide a way of identifying repetition in music, and therefore dictating the structure and repetition of the dance.

Physical Limitations

Another important aspect is that of the physical stability of the robot while performing a dance. For the choreographed dance created in this project, complex moves have been used, as it was possible to test the dance beforehand and see whether the robot remains stable or not. For the non-choreographed dance however, very basic moves have been implemented to ensure stability for whatever random way the robot decides to stack movements. Future work would be needed to keep the robot balanced while performing complex dance movements.

Similarly, each movement had to be tested beforehand, and a standard position has been defined, in which the robot returns after a set of movements. This ensures that the robot performs no illegal moves, such as crossing his hands, since the robot has no fail-safe mechanisms for such situation, and physical damage might be caused to its joints. This issue will probably be resolved by the manufacturers in future upgrades to the robot.

Learning

A limitation to the current research is also the fact that adding basic movements for different meters is time consuming. Ideally, a dancing robot would be able to learn new movements. One possibility would be to learn them by imitating humans, although previous research suggest that this is problematic due to body differences between humans and robots [15]. Alternatively, new moves could be generated (randomly, genetic algorithms, etc.) and they could be judged by humans as to whether they are a fit to the music or not.

Dance as Social Behaviour

To go even further, dance is usually a social activity. Therefore, a robot dancer should be able to synchronize itself to the dance of humans or other robots. The Nao should be able to not only dance by itself, but also together with other dancers (see Appendix B).

5 Conclusion

This research has aimed at investigating the difficulties of enabling the humanoid robot Nao to dance on music. The focus was on creating a dance that is not predefined by the researcher, but which emerges from the music being played to the robot.

The need for this research came from the fact that previous approaches to robot dance in general, and Nao dance in particular, focused on predefined dances built by the researcher. The main goal of this project was to move away from the previous choreographed approaches to Nao dance, and investigate what does it take to make the robot dance in a non-predefined fashion. Moreover, given the fact that previous research has focused mainly on the analysis of musical beat in order to create dance, a secondary goal of this project was to focus not only on the beat, but other elements of music as well, such as the meter.

Both the concept of a choreographed dance and the concept of a non-choreographed dance have been discussed. Moreover, music and music analysis have been investigated to support the creation of the non-predefined dance. Throughout the paper, descriptions of how such aspects have been implemented in practice were given. These implementations have provided proofs of concepts for the ideas discussed.

This research has tried to maintain a holistic view on the subject, and to provide a framework based on which work in this area can be continued in the future. As noted in the last subsection, many other issues have to be addressed before the Nao can perform a truly non-choreographed dance. Such advances would bring more creativity and expressivity to the robot dance.

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Appendix A: Robot Dance 0.8 (beta) by Alexandru Surpatean

This paper describes the behavior of the Nao robot while using the files 'ASurpatean_NaoDance_0.8.xar', 'NaoMacarena.wav', and 'NaoCarmen.wav'. The wave files should be uploaded in the '/srv/ftp/upload' directory of the Nao, and the xar file should be executed in Choregraphe (at the time of writing, the wave files are already present in 'Thor' and 'Frigg').

This presentation has been built for a Nao with three touch sensors on the head. Following is a description of the behaviors that can be achieved.

Stand-by

Execution: Self-executes, every minute.

Description: While in stand-by, the robot will slightly move his head or arm from time to time, giving the impression that he is 'alive' even thought he is not currently used.

Repetition: Every minute, one of nine random movements.

Hello

Execution: Front Touch Sensor.

Description: The robot waves his right hand and says 'Hello dear humans, my name is Thor!'

Repetition: Predefined from start to finish, each repetition generates the same behavior.

Macarena (choreographed)

Execution: Middle Touch Sensor.

Description: The Nao dances on the 'Macarena' song.

Repetition: The dance is choreographed from start to finish; each repetition of the behavior generates the same movements.

Note: The robot will move his whole body! On a glossy surface (normal table) this will usually not create any problems. On a ruff surface (wood plate), the robot can fall on his face. Keep your hand and apply pressure on the back of one of his ankles to keep him stable.

Carmen (non-choreographed)

Execution: Back Touch Sensor.

Description: The Nao dances on the 'Carmen' song.

Repetition: From a list of predefined movements, the robot will build his own choreography. Each repetition will generate a different set of movements. Currently, this is based on simple randomness.

Note: In this version of the code, the music is not analyzed on-the-fly, but the information is predefined in the code. This means that the robot can dance only on the provided piece of music (quadruple meter dance on music with approx 135 BPM converted to approx 68 danceable PBM).

Contact

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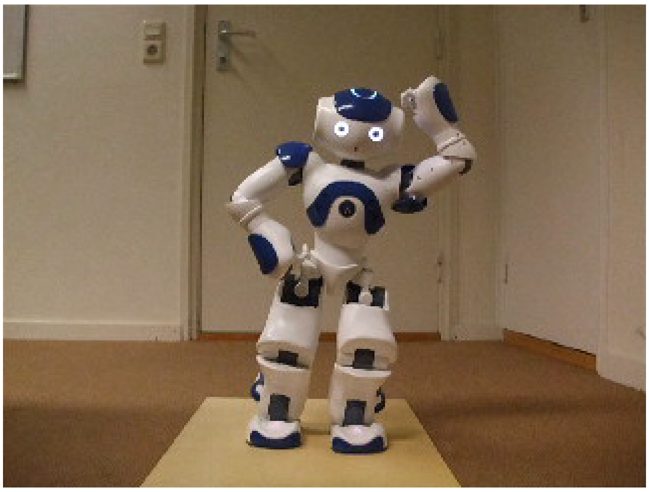
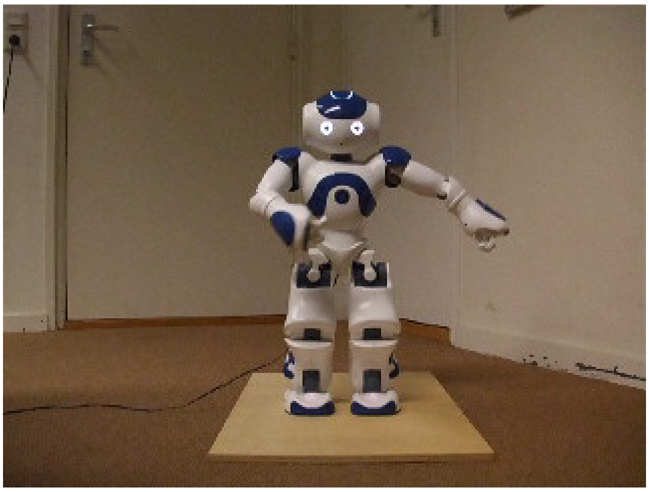
Appendix B: Dance Demonstrations

Besides the public displays of the robot dances, movies have been made of the Nao robot performing its moves, in order to capture the practical implementation of the concepts. These movies are available online at http://alex.surpatean.eu/dance/



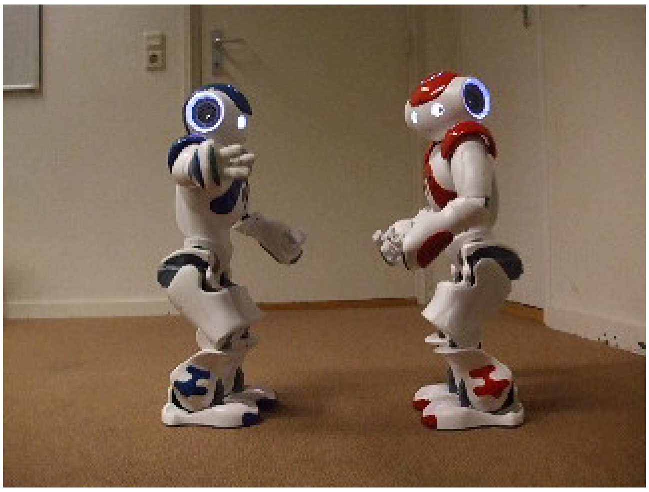
Dance Lesson 1 - Imitate the Humans!

The first video depicts the Nao performing its dance on the 'Macarena' song by 'Los del Rio'. This video aims to depict a choreographed dance.



Dance Lesson 2 - Improvise!

In the second video, the Nao performs his non-choreographed dance on the 'Habanera' aria from the 'Carmen' opera by Georges Bizet, three times. The aim of the video is to illustrate how the movements change even though the music is the same for each repetition.



Dance Lesson 3 - Socialize!

The third video presents a perspective of the future. Two Nao robots (a pair of a blue and a red Nao) perform their non-choreographed 'Carmen' dance in sync.